Benthic Survey of Commercial Aggregate Mining Leases in Central San Francisco Bay and Western Delta

  

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Executive Summary

Within the San Francisco Bay-Delta (Bay-Delta), dredging of marine sediments is routinely conducted for the creation and maintenance of harbors, deep water shipping channels, and for use as commercial aggregate. Currently, sand mining within the Bay-Delta only occurs within defined lease locations within Central Bay, Middle Ground Shoal, and along Suisun Bay navigation channels. Over a twelve-month period beginning in March 2002 and ending in February 2003, 1.6 million cubic yards of material were extracted during 843 mining events at these locations. Although 1.6 million cubic yards of extracted material per year is reported by the mining companies to be representative of annual extraction volumes, state and federal permits allow up to 2.1 million cubic yards of material to be extracted annually (Hanson 2004; NOAA 2006). Until recently, three companies were actively engaged in sand mining activities: Hanson Aggregate Mid-Pacific, Inc. (Hanson Aggregate), RMC/CEMEX, Inc., and Jericho Products, Inc./Morris Tug and Barge (Jericho/MT).

Because of concerns about the potential effect on benthic biological communities in the Bay-Delta as a result of commercial aggregate mining and a lack of applicable scientific studies concerning the subject, Applied Marine Sciences, Inc. (AMS) was requested to conduct a field survey and data analysis to evaluate the effects of sand mining on these biological resources. This study was designed to (1) characterize benthic communities inhabiting sand mining leases and unmined control sites, (2) identify differences between communities inhabiting mining leases and control sites, and (3) obtain a better understanding of the effects of sand mining on benthic communities in Central San Francisco Bay and the western Delta and their rates of recovery following sand mining events.

AMS conducted sampling during August 19-22 and 25-26 in 2008. Twenty five sites (*i.e.,* 20 in mining leases and five controls) were sampled in Central Bay and 15 sites (*i.e.*, ten in mining leases and five controls) were sampled in the Delta. From the twenty five samples collected from the nine Central Bay mining leases and two control areas, 107 taxa were identified. Benthic communities were numerically dominated by nematoda, followed by polychatea, amphipoda, and bivalvia, which averaged 884, 484, 269 and 185 animals/m^2, respectively. Total organism densities averaged nearly 2,000/m^2. From the 15 samples collected from the Delta, only 16 taxa were identified. Benthic communities in the Delta were numerically dominated by bivalvia, followed by polychatea and amphipoda, which averaged 369, 37 and 25 animals/m^2, respectively. Total organism densities averaged 472/m^2.

There were large differences among Central Bay sites in the numbers of taxa (species richness), numbers of organisms (total abundance), and sediment characteristics. For example, two sites, 7779W-02 and 7779W-04, had 4,000 organisms/m^2 and greater than 40 taxa, while site 2036-01 also had greater than 4,000 organisms/m^2, but had only 28 taxa. In contrast, site 7780N-01 had only 307 organisms/m^2 and 10 taxa and site 709N-03 had only 343 organisms/m^2 and 7 taxa. Sites 7779W-02 and 7779W-04 also had coarser sediments than did other sites, with 34.1% and 48.7% medium gravel, respectively. Multivariate statistical clustering of all sites in Central Bay, based upon the abundances of dominant taxa, revealed five groupings. These five groupings did not correspond to individual leases or control sites.

There were relatively smaller differences among sites in the numbers of taxa and numbers of organisms in the Delta than in Central Bay. Site 7781E-02 had greater than 7 taxa and 800 organisms/m^2. Site DCMG-03, located in the control area closest to Middle Ground Shoal, also had greater than 800 organisms/m^2, but had only 4 taxa. In contrast, site 7781W-01 had only 54 organisms/m^2 and 2 taxa and site DCMG-05 had only 325 organisms/m^2 and 3 taxa. Multivariate statistical clustering of sites based upon abundances of dominant taxa revealed three groupings, which did not correspond to mining leases or control sites.

The benthic communities observed in Central Bay and the western Delta are generally consistent with those reported for these regions by other studies. The Central Bay study area is deeper and contains

coarser sediments than previously sampled by other programs, and contained numerous taxa that had not been listed as characteristic for Central Bay by previous investigators. In both the Central Bay and Delta, densities of benthic taxa appeared to be predominantly correlated with sediment grain size. In the Delta, salinity appears to also be an important variable controlling abundances of some taxa

The area of Central Bay where sand mining occurs does not appear to be highly degraded due to organic enrichment or elevated contaminant levels. This conclusion is based on an assessment of benthic community taxa, relative to their sensitivity or tolerance to environmental stress, using best professional judgment indicators as presented by Weisberg *et al.* 2008.

No substantial effects of mining on the benthic infaunal communities in either Central Bay or the West Delta mining leases were suggested by study results. The only potential effects of aggregate mining detected in Central Bay included a reduction in medium sand at sites that had been mined, and increasing densities of *Nephtys ?californiensis* , *Megamoera subtener,* and total amphipoda with increasing time since the previous mining. Although *N. ?californiensis* and *M. subtener* were among the taxa that contributed >0.15% to total organism abundances and occurred at >15% of sites, they were neither very abundant nor widespread. *N. ?californiensis* and *M. subtener* averaged only 0.26% and 1.9% of total organism abundance, respectively, and each was found at five sites.

Sampling sites that had previously been mined within three years of sampling for the current study exhibited no biological characteristics suggesting effects from sand mining. The absence of clear mining effects indicates that biological effects that do occur are either spatially very small or communities recover to the point of being indistinguishable from those in unmined sites within two years. The rapid recovery of benthic communities to pre-mining conditions could be due, in part, to natural environmental conditions that appear to disturb benthic communities throughout the area of Central Bay where sand mining occurs. The highly dynamic physical environment in the area of Central Bay where sand mining occurs appears to prevent benthic infaunal organisms from achieving a high level of community development. Also, rapid recolonization of mined tracks can occur not only by larval recruitment, but also by immigration from surrounding unmined sediments, either through active movement by individual organisms or through transport by slumping sediments.

1 Introduction

1.1 Study Background

Within the San Francisco Bay-Delta (Bay-Delta), dredging of marine sediments is routinely conducted for the creation and maintenance of harbors, deepening of shipping channels, and for use as commercial aggregate. Dredging for harbors and shipping channels has been conducted in San Francisco Bay since the 1800s, whereas the dredging of sand for commercial construction activities (sand mining) has only been conducted since the 1930s (Hanson 2004). Sand that has been commercially dredged from Central San Francisco Bay and the western Delta is routinely used for construction fill material and for making concrete.

Currently, sand mining within the Bay-Delta only occurs within defined lease locations within Central Bay, Middle Ground Shoal, and along Suisun Bay channels. Over a twelve-month period beginning in March 2002 and ending in February 2003, 1.6 million cubic yards of material were extracted during 843 mining events at these locations. Although 1.6 million cubic yards of extracted material per year is reported by the mining companies to be representative of annual extraction volumes, state and federal permits allow up to 2.1 million cubic yards of material to be extracted annually (Hanson 2004; NOAA 2006). Until recently, three companies were actively engaged in sand mining activities: Hanson Aggregate Mid-Pacific, Inc. (Hanson Aggregate), RMC/CEMEX, Inc., and Jericho Products, Inc./Morris Tug and Barge (Jericho/MT).

In 2007, leases issued by the California State Lands Commission (CSLC) for the use of State-owned tidal and subtidal lands for commercial sand extraction were about to expire. Hanson Aggregate and Jericho/MT (the applicants) submitted an application to the CSLC for renewal of ten leases in Central Bay, two leases in Suisun Marsh, and a private lease at Middle Ground Shoal, in Suisun Bay. Per the California Environmental Quality Act (CEQA), the CSLC required an environmental assessment of potential effects and impacts of commercial sand mining activities. Because of concerns about the potential effect on benthic biological communities in the Bay-Delta as a result of commercial aggregate mining and a lack of applicable scientific studies concerning the subject, Applied Marine Sciences, Inc. (AMS) was requested to conduct a field survey and data analysis to evaluate the effects of sand mining on these biological resources.

In order to assess the effects of sand mining on benthic communities, this study was designed to achieve the following objectives:

- Characterize benthic communities inhabiting sand mining leases and unmined control sites,
- Identify differences between communities inhabiting mining leases and control sites,
- Obtain a better understanding of the effects of sand mining on benthic communities in Central San Francisco Bay and the western Delta and their rates of recovery following sand mining events.

This report presents the results of sediment sampling conducted in Central San Francisco Bay (Central Bay) and in Suisun Bay and Suisun Marsh (Delta).

1.2 Description of Mining Activities

Hanson Aggregate (Hanson Aggregate) and Jericho/Morris Tug and Barge (Jericho/MTB) use an assortment of hydraulic equipment to extract sand from the seafloor of the Bay-Delta (Hanson 2004). In general, a steel dredge pipe (13-20 inches in diameter), affixed with a 3 x 4-foot drag head, is lowered to the seafloor from a hinged point on the deck of the barge. The dredge pipe is primed with seawater and a sand/water slurry is pumped into a rectangular chute located above the hopper barge and running the length of the barge. Screened gates (meshes 3/8"- 3/4" in size) are evenly distributed along the bottom of the rectangular chute to size and disperse the material into the hopper barge. Oversized material and debris are pumped to the end of this rectangular chute where it connects to a pipe that directs the material back to the Bay under the barge. Prior to the commencement of mining, the hopper barge is filled with water to provide added maneuvering stability, allowing trapped fines to remain suspended and flow overboard through weirs or flashboards located in the walls of the barge. A "potholing" method is the normal operation, wherein the barge attempts to remain stationary or move very slowly forward while extracting sand, remaining onsite until visual observations and onboard measurements indicate the grain size of the mined material has exceeded the targeted texture. A typical mining event load is 1,850 to 2,400 cubic yards of sand, and can take several hours to complete. Operations can be conducted either day or night (Hanson 2004). During ballasting operations, the drag head is required by State permit to be located no higher off the seafloor than three feet (BCDC 2008).

Using the prevailing equipment, mining operations can technically occur in water depths as shallow as 17 feet and as deep at 90 feet, although existing permit conditions only allow mining in water depths greater than 30 feet (BCDC 2008). In the Central Bay leases, mining occurs in an area roughly bounded by Angel Island to the east, the Tiburon peninsula and Richardson Bay to the north, the Golden Gate to the west and the San Francisco Embarcadero to the south (Figure 2-1). In the Delta, two State leases and one privately owned lease (Middle Ground Shoal) are located east of Carquinez Strait (Figure 2-2), and mining in these areas occurs primarily along the upper edge of the shipping channel, along a band of the channel where decreasing water velocity allows the coarser sand fractions to settle out.

2 Sampling and Analytical Methodologies

2.1 Field Sampling

AMS conducted sampling during August 19-22 and 25-26 in 2008. Twenty five sites (*i.e.,* 20 in mining leases and five controls) were sampled in Central Bay and 15 sites (*i.e.*, ten in mining leases and five controls) were sampled in the Delta. Sampling sites were randomly positioned prior to the cruise. Sampling sites in leased areas were located in two ways. First, 10 sites in Central Bay were selected near the ends of track lines of known mining events, based on positioning data provided by Hanson Aggregate. In some cases, post-sampling analysis indicated the sample had been collected outside the mined area, resulting in fewer than the intended number of samples from known mining areas. Second, 10 sample locations were randomly selected from within the leased areas and allocated to each lease area roughly in proportion to the size of the lease. Five sites were randomly located within control areas, also in rough proportion to the size of each control area. Due to relatively infrequent mining events in the Delta leases, only two sampling sites were located within areas that had recently been mined. Sediment samples were collected for benthic infauna, grain size and total organic carbon (TOC), and a water-column profile was collected at each site with a Sea-Bird SBE 19 CTD profiler.

In some cases, it was necessary to move the site, such as when the sediment texture in a sample observed in the field was either too fine (especially in the case of control samples) or too coarse, or the preselected site was too deep to represent areas targeted for mining. Consequently, several sites were moved during the cruise within a 100-500 m radius of the target coordinates. The sampling crew attempted to sample within 100 m along the trackline of the target position in previously mined areas. If preselected control sites or leased sites that had not recently been mined were unsatisfactory due to sediment texture or depth, new sites were arbitrarily sampled until the sediment texture and depth criteria were met.

The crew and schedule for field sampling are shown in Table 2-1 and Table 2-2, respectively. The field cruise occurred in two segments, with four days spent in the Central Bay and two days in the Delta. Table 2-3 provides details on each sample location, including sediment characteristics; Table 2-4 shows sea and weather conditions and tables 2-5 and 2-6 show water quality conditions at each Central Bay and Delta sample site, respectively.

Table 2-1. Personnel for the SLC sand mining cruise, August 19-26, 2008

Name	Affiliation	Duties
Jay Johnson	Applied Marine Sciences, Inc. (AMS)	Cruise Manager (8/19-8/22; 8/25-8/26)
Paul Salop	Applied Marine Sciences, Inc. (AMS)	Sample collection (8/22; 8/25-8/26)
Bryan Bemis	Applied Marine Sciences, Inc. (AMS)	Sample collection (8/19-8/22; 8/26)
Clare Dominik	Applied Marine Sciences, Inc. (AMS)	Sample collection (8/19-8/22; 8/25-8/26)
Sarah Lowe	San Francisco Estuary Institute (SFEI)	Sample collection (8/20)
Nicole David	San Francisco Estuary Institute (SFEI)	Sample collection (8/21)
David Morgan	Romberg Tiburon Center (RTC)	Captain; *RV Questuary* (8/19-8/22; 8/25-8/26)

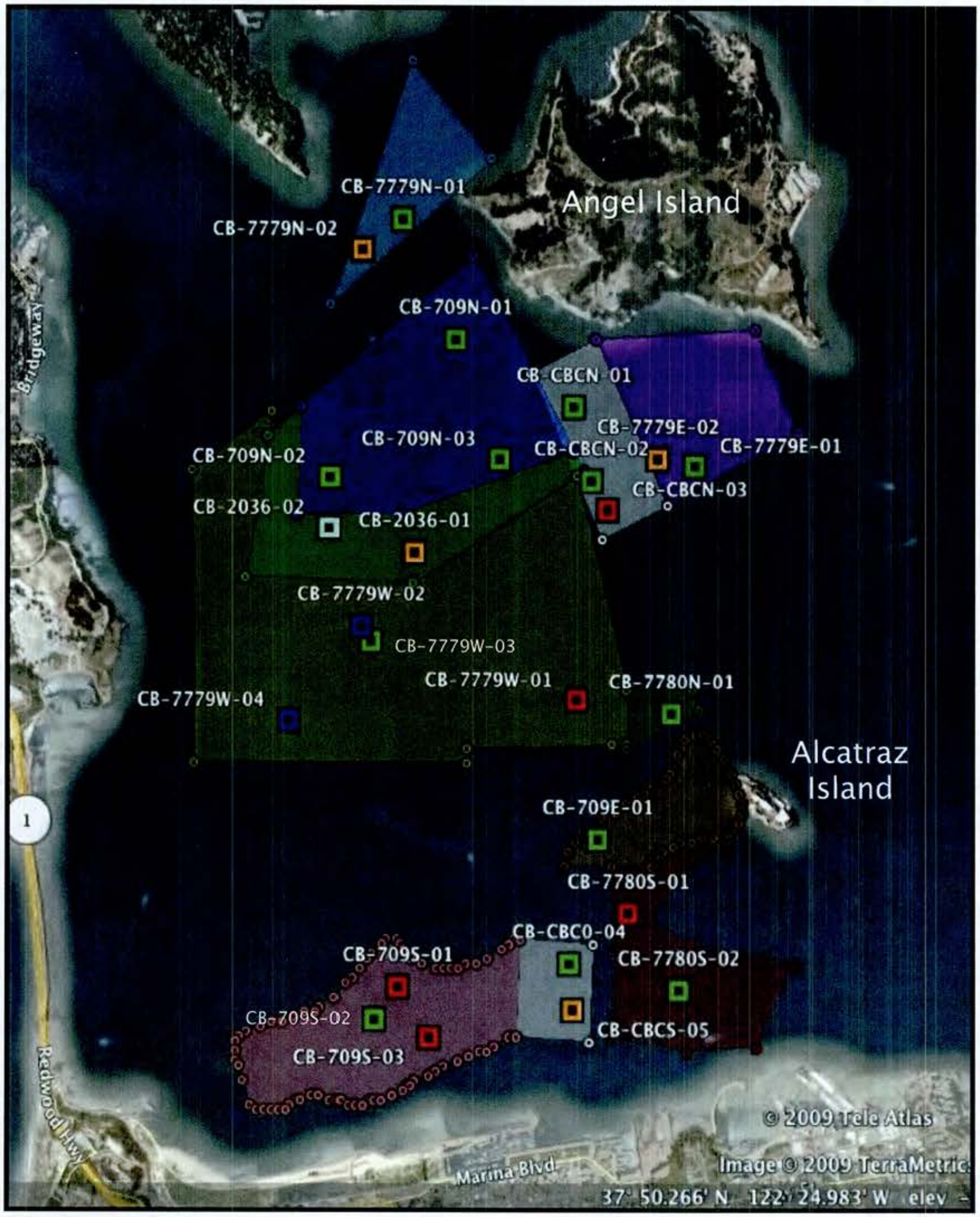

Figure 2-1. Lease areas and sampling sites in Central Bay. Colors of square site symbols correspond to clusters shown in Figure 3-1.

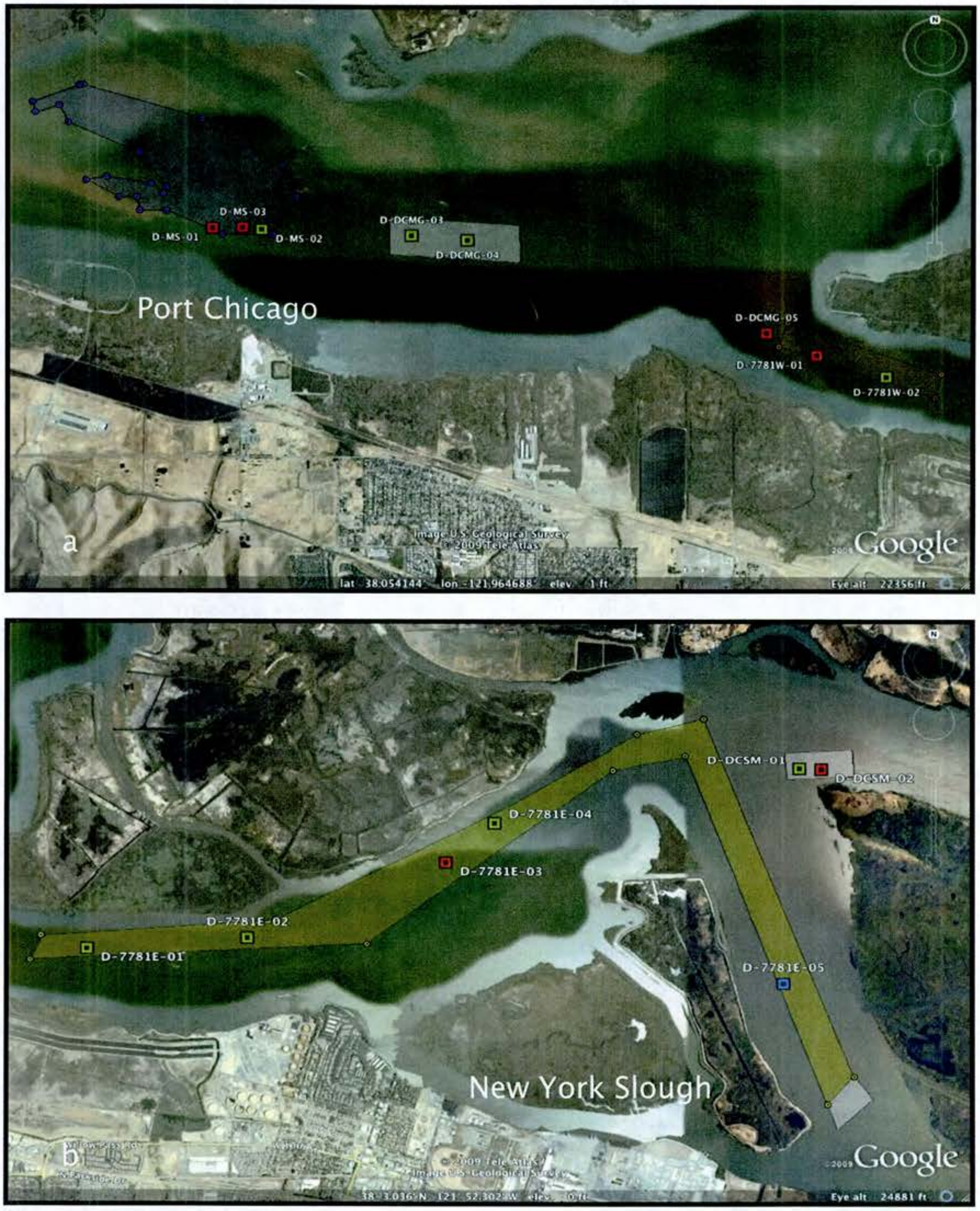

Figure 2-2. Lease areas and sampling sites in western (a) and eastern (b) portions of the Delta sampling area. Colors of square site symbols correspond to clusters shown in Figure 3-5.

Table 2-2. Sampling activities for SLC sand mining cruise, August 19-26, 2008

Date	Time	Activity
August 19, 2008	0700-0808	Mobilized gear at Paradise Cay Marina
	1147-1230	Sampled site CB-7780N-01
	1303-1515	Processed remaining samples at Paradise Cay Marina
August 20, 2008	0600-0618	Mobilized gear at Paradise Cay Marina
	0652-0717	Sampled site CB-7779W-02
	0717-0730	Sampled site CB-7779W-03
	0733-0745	Sampled site CB-7779W-04
	0749-0810	Sampled site CB-7779W-01
	0816-0835	Sampled site CB-2036-02
	0845-0850	Sampled site CB-2036-01
	0903-0950	Sampled site CB-709N-01
	1010-1028	Sampled site CB-709N-03
	1032-1041	Sampled site CB-709N-02
	1116-1449	Processed samples at Paradise Cay Marina
August 21, 2008	0605-0614	Mobilized gear at Paradise Cay Marina
	0643-0732	Sampled site CB-7779N-02
	0738-0751	Sampled site CB-7779N-01
	0800-0811	Sampled site CB-7779E-01
	0815-0830	Sampled site CB-7779E-02
	0840-0851	Sampled site CB-CBCN-03
	0856-0903	Sampled site CB-CBCN-02
	0910-0915	Sampled site CB-CBCN-01
	0930-0941	Sampled site CB-709E-01
	0948-100	Sampled site CB-7780S-02
	1009-1015	Sampled site CB-7780S-01
	1047-1420	Processed samples at Paradise Cay Marina
August 22, 2008	0600-0615	Mobilized gear at Paradise Cay Marina
	0652-0715	Sampled site CB-709S-03
	0725-0750	Sampled site CB-709S-02
	0753-0803	Sampled site CB-709S-01
	0808-0824	Sampled site CB-CBCS-05
	0830-0836	Sampled site CB-CBCS-04
	0913-1150	Processed samples at Paradise Cay Marina
August 25, 2008	0830-0910	Mobilized gear at Pittsburg Marina
	0943-1015	Sampled site D-MS-03
	1025-1035	Sampled site D-MS-01
	1045-1054	Sampled site D-MS-02
	1134-1145	Sampled site D-DCMG-04
	1150-1200	Sampled site D-DCMG-03
	1210-1230	Sampled site D-DCMG-05
	1306-1310	Sampled site D-7791W-01
	1315-1322	Sampled site D-7791W-02
	1336-1715	Processed samples at Pittsburg Marina
August 26, 2008	0600-0630	Mobilized gear at Pittsburg Marina
	0650-0730	Sampled site D-7781E-05
	0735-0750	Sampled site D-DCSM-02
	0750-0802	Sampled site D-7791W-01
	0807-0840	Sampled site D-7781E-04
	0845-0905	Sampled site D-7781E-03
	0910-0955	Sampled site D-7781E-02
	1000-1020	Sampled site D-7781E-01
	1030-1330	Processed samples at Pittsburg Marina
	1330-1400	Demobilized gear at Pittsburg Marina

2.1.1 Sample Evaluation

Sediment samples were collected using a 0.1 m^2 modified Van Veen grab. In the field, the grab was split into two approximately equal portions, with one side of the grab used for collecting physical and chemical analysis samples and the other half for benthic infauna.

Quality control procedures were used to ensure the collection of undisturbed samples of adequate volume. Upon retrieval of the grab, the acceptability of the sample was determined by evaluating the type of sediment, sample condition, and depth of penetration. Sample condition was judged using criteria for surface disturbance due to sediment leakage from the grab. An acceptable sample condition was characterized by an even surface with minimal disturbance and little or no leakage of the overlying water, which washes sediment from the grab surface. Samples with heavily canted surfaces were deemed unacceptable. Samples with a large amount of "humping" along the midline of the grab, which indicates washing from the sample periphery during retrieval, were also unacceptable. Although some humping will be evident in samples taken from firm sediment where penetration has been poor, this can be due to the closing action of the grab and is not necessarily evidence of unacceptable washing.

The following conditions led to sample rejection:

- There was a rock, shell fragment, or bivalve wedged between the jaws of the grab, allowing the sample to wash out,
- The sample surface was significantly disturbed,
- The sample was uneven from side to side, indicating that the grab was tilted when it penetrated the sediment,
- The surface of the sample was in contact with the top doors of the grab, indicating over-penetration of the grab and possible loss of material around the doors,
- The penetration depth of the grab was insufficient to provide enough sediment for analyses.

If the sample condition was acceptable, then the overlying water was carefully drained off into a sample tray and the depth of penetration was determined by inserting a plastic ruler into the sediment at the grab midline and measuring to the nearest 0.5 cm. Sediment penetration depth was required to be at least 5 cm. Overlying water in samples intended for infaunal analyses was drained by slightly opening the jaws of the grab and allowing the water to run off into the sample tray.

2.1.2 Initial Processing of Benthic Infaunal Samples

With the grab jaws still closed, a thin metal plate was inserted into the sediment at the mid-line of the grab, directly above and in line with the jaw opening. This plate split the sample into two subsamples. One subsample was used to collect the sediment grain size and TOC samples, and the other subsample was used to collect benthic infauna, resulting in a sampler area of approximately 0.05 m^2.

Table 2-3. Sampling coordinates, depth, grab penetration, and sediment character of sampling sites for SLC Sand Mining Cruise, August 19-26, 2008

Lease	Site Name	Date Sampled	Latitude (WGS84)	Longitude (WGS84)	Water Depth[1] (m)	Grab Penetr. Depth (cm)	Sediment Character
					Central Bay		
PRC 2036	CB-2036-01[2,3]	8/20/2008	37° 50.455	122° 26.977	24.2	9	Fine to coarse sand with large shells, pebbles, cobbles
	CB-2036-02[2]	8/20/2008	37° 50.542	122° 27.364	23.1	9	Fine sand with shell aggregates and pebbles
PRC 709 East	CB-709E-01	8/21/2008	37° 49.478	122° 26.127	19.6	5	Fine to coarse sand with shells (coarser toward bottom)
PRC 709 North	CB-709N-01	8/20/2008	37° 51.183	122° 26.791	15.6	10	NR[4]
	CB-709N-02	8/20/2008	37° 50.713	122° 27.361	19.0	9	Fine to coarse sand
	CB-709N-03	8/20/2008	37° 50.776	122° 26.585	16.7	9	Medium to coarse sand
PRC 709 South	CB-709S-01[2]	8/22/2008	37° 48.973	122° 27.040	26.4	8.5	NR[4]
	CB-709S-02[2]	8/22/2008	37° 48.864	122° 27.152	23.0	10.5	Fine sand with silt
	CB-709S-03[2]	8/22/2008	37° 48.800	122° 26.895	17.8	8	Fine to medium sand with clay balls on surface
PRC 7779 East	CB-7779E-01	8/21/2008	37° 50.754	122° 25.689	23.9	10	Fine to medium sand with some clay
	CB-7779E-02	8/21/2008	37° 50.778	122° 25.860	20.1	9	Medium sand with some fines
PRC 7779 North	CB-7779N-01	8/21/2008	37° 51.593	122° 27.037	25.0	9.5	Fine to medium sand
	CB-7779N-02	8/21/2008	37° 51.490	122° 27.221	30.3	8	Unconsolidated fine to medium sand with shell debris
PRC 7779 West	CB-7779W-01[2]	8/20/2008	37° 49.954	122° 26.224	26.2	>5	NR[4]
	CB-7779W-02	8/20/2008	37° 50.204	122° 27.218	26.4	6	Coarse sand, cobbles, pebbles, shells
	CB-7779W-03[2]	8/20/2008	37° 50.154	122° 27.172	29.7	9	Coarse sand, cobbles, pebbles, shells
	CB-7779W-04	8/20/2008	37° 49.881	122° 27.544	40.2	6	Large cobble, pebbles, shells
PRC 7780 North	CB-7780N-01	8/19/2008	37° 49.908	122° 25.792	22.7	7	Unconsolidated medium and fine sand
PRC 7780 South	CB-7780S-01	8/21/2008	37° 49.226	122° 25.986	22.8	9	Fine to medium sand
	CB-7780S-02	8/21/2008	37° 48.964	122° 25.753	24.5	9	Fine to medium sand; coarser material deeper (pebbles and shells)
Central Bay Control	CB-CBCN-01	8/21/2008	37° 50.954	122° 26.246	14.5	10	Fine to medium sand with some shell hash and large shells
	CB-CBCN-02	8/21/2008	37° 50.703	122° 26.164	18.3	10	Fine to medium sand
	CB-CBCN-03	8/21/2008	37° 50.604	122° 26.089	20.7	10	Fine to medium sand

Lease	Site Name	Date Sampled	Latitude (WGS84)	Longitude (WGS84)	Water Depth[1] (m)	Grab Penetr. Depth (cm)	Sediment Character
	CB-CBCS-04	8/22/2008	37° 49.053	122° 26.257	21.4	7.5	Fine to medium sand (some coarse grains) with shells
	CB-CBCS-05	8/22/2008	37° 48.896	122° 26.240	22.4	8	Fine to coarse sand
					Delta		
PRC 7781 East	D-7781E-01	8/26/2008	38° 02.847	121° 54.812	11.6	9	Fine to medium sand
	D-7781E-02	8/26/2008	38° 02.903	121° 53.808	10.3	9	Fine to medium sand
	D-7781E-03[2]	8/26/2008	38° 03.314	121° 52.574	16.4	10	Fine to medium sand with some pebbles
	D-7781E-04[2]	8/26/2008	38° 03.537	121° 52.254	18.8	10	Fine to medium sand with pebbles deeper and *Corbicula* clams
	D-7781E-05	8/26/2008	38° 02.646	121° 50.471	5.0	10	Fine sand with *Corbicula* clams
PRC 7781 West	D-7781W-01	8/25/2008	38° 02.975	121° 56.050	15.4	10	Fine sand
	D-7781W-02	8/25/2008	38° 02.871	121° 55.657	15.8	>5	Fine to medium sand
Delta Control	D-DCSM-01	8/26/2008	38° 03.826	121° 50.364	9.3	12	Fine to coarse sand with peat at bottom; slight sulfur smell
	D-DCSM-02	8/26/2008	38° 03.821	121° 50.226	8.5	>5	Medium to coarse sand
	D-DCMG-03	8/25/2008	38° 03.563	121° 58.324	12.0	5	Fine to medium sand
	D-DCMG-04	8/25/2008	38° 03.540	121° 58.011	10.8	10	Fine sand with some clay
	D-DCMG-05	8/25/2008	38° 03.085	121° 56.334	13.4	>5	NR[4]
Middle Shoal	D-MS-01	8/25/2008	38° 03.599	121° 59.431	12.3	>5	Fine to medium sand
	D-MS-02	8/25/2008	38° 03.592	121° 59.160	11.0	8	Fine to medium sand
	D-MS-03	8/25/2008	38° 03.602	121° 59.327	11.4	9	Fine to medium sand over densely consol. clay; many small bivalves

Note[1] : Connected to mean lower low water (MLLW)
Note[2] : Station located along previously mined tracks
Note[3] : Sample collected near actively mining barge
Note[4] : Not Recorded

Table 2-4. Sea and weather conditions at sampling sites during SLC Sand Mining Cruise, August 19-26, 2008

Lease	Site Name	Date Sampled	Sea State	% Overcast	Wind (speed, direction from)	Current (speed, direction toward)
PRC 2036	CB-2036-01	8/20/2008	<1 ft chop	100	9 kts 218°	1.2 kts 86°
	CB-2036-02	8/20/2008	<1 ft chop	100	7 kts 220°	0.6 kt 285°
PRC 709 East	CB-709E-01	8/21/2008	2-3 ft chop	100	13 kts 223°	0.7 kt 53°
	CB-709N-01	8/20/2008	<1 ft chop	100	9 kts 190°	0.6 kt 32°
	CB-709N-02	8/20/2008	<1 ft chop	100	21 kts 226°	0.9 kt 315°
	CB-709N-03	8/20/2008	<1 ft chop	100	7 kts 211°	2 kts 180°
PRC 709 South	CB-709S-01	8/22/2008	2-3 ft swell	90	5 kts 189°	0.8 kt 259°
	CB-709S-02	8/22/2008	1-2 ft chop	90	11 kts 228°	0.9 kt 47°
	CB-709S-03	8/22/2008	1-2 ft chop	90	12 kts 219°	0.3 kt 116°
PRC 7779 North	CB-7779E-01	8/21/2008	1-2 ft chop	30	11 kts 231°	1.9 kts 235°
	CB-7779E-02	8/21/2008	1 ft chop	60	14 kts 218°	1.6 kts 60°
	CB-7779N-01	8/21/2008	<1 ft chop	20	4 kts 145°	0.5 kt 281°
	CB-7779N-02	8/21/2008	<1 ft chop	20	7 kts 45°	1 kt 221°
PRC 7779 West	CB-7779W-01	8/20/2008	<1 ft chop	100	10 kts 94°	2.3 kts 68°
	CB-7779W-02	8/20/2008	<1 ft chop	100	NR[1]	NR[1]
	CB-7779W-03	8/20/2008	<1 ft chop	100	11 kts 346°	1.3 kts 256°
	CB-7779W-04	8/20/2008	<1 ft chop	100	9 kts 234°	1.3 kts 246°
PRC 7780 North	CB-7780N-01	8/19/2008	<1 ft chop	95	8 kts 230°	2.8 kts 60°
PRC 7780 South	CB-7780S-01	8/21/2008	2 ft chop	100	13 kts 224°	1 kt 94°
	CB-7780S-02	8/21/2008	2-3 ft chop	100	20 kts 289°	1.7 kts 245°
Central Bay Control	CB-CBCN-01	8/21/2008	1-2 ft chop	100	12 kts 212°	0.5 kt 357°
	CB-CBCN-02	8/21/2008	2-3 ft chop	100	14 kts 229°	1.1 kts 249°
	CB-CBCN-03	8/21/2008	1-3 ft chop	100	13 kts 237°	1.1 kts 280°
	CB-CBCS-04	8/22/2008	2-3 ft chop	75	10 kts 221°	0.6 kt 243°
	CB-CBCS-05	8/22/2008	2-3 ft chop	80	6 kts 139°	0.9 kt 265°
PRC 7781 East	D-7781E-01	8/26/2008	<1 ft chop	0	6 kts 241°	0.2 kt 61°
	D-7781E-02	8/26/2008	<1 ft chop	0	6 kts 266°	0.4 kt 346°
	D-7781E-03	8/26/2008	<1 ft chop	0	7 kts 305°	0.9 kt 194°
	D-7781E-04	8/26/2008	<1 ft chop	0	9 kts 276°	1 kt 235°
	D-7781E-05	8/26/2008	<1 ft chop	0	12 kts 279°	0.6 kt 137°
PRC 7781 West	D-7781W-01	8/25/2008	1 ft chop	0	17 kts 238°	1.5 kts 95°
	D-7781W-02	8/25/2008	1 ft chop	0	20 kts 281°	0.7 kt 112°
Delta Control	D-DCSM-01	8/26/2008	<1 ft chop	0	9 kts 303°	0.9 kt 256°
	D-DCSM-02	8/26/2008	1 ft chop	0	12 kts 32°	1.5 kts 120°
	D-DCMG-03	8/25/2008	1 ft chop	0	16 kts 263°	1.6 kts 115°
	D-DCMG-04	8/25/2008	1 ft chop	0	13 kts 270°	1.5 kts 262°
	D-DCMG-05	8/25/2008	1-2 ft chop	0	10 kts 300°	1.5 kts 122°
Middle Shoal	D-MS-01	8/25/2008	1 ft chop	0	1.3 kts 237°	1.4 kts 85°
	D-MS-02	8/25/2008	1 ft chop	0	15 kts 270°	1.4 kts 78°
	D-MS-03	8/25/2008	1 ft chop	0	16 kts 273°	1.4 kts 85°

Note[1]: Not recorded

Table 2-5. Summary of physical water quality parameters for Central Bay sites on the sand mining cruise during August 19-22, 2008

Depth Group[1]	Analyte	CB-2036-01	CB-2036-02	CB-709E-01	CB-709N-01	CB-709N-02	CB-709N-03	CB-709S-01	CB-709S-02	CB-709S-03	CB-7779E-01	CB-7779E-02	CB-7779N-01	CB-7779N-02	CB-7779W-01	CB-7779W-02
Sfc	Temp (°C)	16.7	16.7	16.9	16.5	16.6	16.8	16.6	16.4	16.1	16.8	16.9	16.7	16.6	16.5	16.2
	Cond (S/m)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
	Sal (psu)	31.9	31.9	32.1	32.1	32.1	31.9	32.3	32.4	32.6	32.1	31.9	32.0	32.2	32.2	32.3
	Ox (mg/L)	7.0	7.0	6.2	7.2	6.9	6.8	7.0	7.3	7.7	6.7	7.3	6.6	6.3	6.7	6.6
	Back (ftu)	3.9	3.9	4.1	5.8	3.4	3.6	4.0	3.4	2.8	3.4	3.9	3.5	3.4	4.9	3.6
Mid	Temp (°C)	16.4	16.4	16.7	16.5	16.4	16.5	16.2	16.1	15.9	16.7	16.7	16.5	16.3	16.4	16.2
	Cond (S/m)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
	Sal (psu)	32.2	32.2	32.2	32.1	32.2	32.1	32.6	32.7	32.7	32.1	32.1	32.2	32.4	32.3	32.4
	Ox (mg/L)	7.1	7.1	6.6	7.2	7.0	6.9	7.1	7.2	7.5	7.1	7.2	7.1	7.1	7.1	6.6
	Back (ftu)	3.9	3.8	4.3	3.7	3.6	3.7	4.1	3.3	3.9	3.4	3.6	3.5	3.6	5.4	3.6
Bot	Temp (°C)	16.3	16.3	16.4	16.2	16.3	16.3	16.1	16.0	15.9	16.3	16.4	16.4	16.1	16.2	16.1
	Cond (S/m)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
	Sal (psu)	32.3	32.2	32.4	32.3	32.3	32.2	32.6	32.7	32.8	32.3	32.3	32.3	32.6	32.4	32.4
	Ox (mg/L)	7.1	7.1	6.9	7.2	7.1	7.0	7.2	7.3	8.0	7.2	7.3	7.2	7.3	7.3	6.7
	Back (ftu)	3.9	3.7	4.6	3.6	3.8	4.2	5.0	3.9	7.2	3.7	3.8	3.6	4.9	5.1	3.7

Depth Group[1]	Analyte[2]	CB-7779W-03	CB-7779W-04	CB-7780N-01	CB-7780S-01	CB-7780S-02	CB-CBCN-01	CB-CBCN-02	CB-CBCN-03	CB-CBCS-04	CB-CBCS-05
Sfc	Temp (°C)	16.2	16.2	15.7	17.0	17.0	16.9	17.0	17.0	16.8	16.7
	Cond (S/m)	4.1	4.1	4.1	4.2	4.1	4.1	4.1	4.1	4.2	4.2
	Sal (psu)	32.3	32.4	32.6	32.1	32.0	31.9	31.8	31.8	32.3	32.3
	Ox (mg/L)	7.3	7.0	7.2	6.3	7.1	6.8	7.3	8.8	6.5	6.6
	Back (ftu)	3.8	3.8	3.5	3.6	4.5	3.7	3.7	3.5	4.1	4.3
Mid	Temp (°C)	16.2	16.2	15.6	16.8	16.9	16.7	16.7	16.8	16.7	16.5
	Cond (S/m)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.2	4.1
	Sal (psu)	32.4	32.4	32.6	32.1	32.1	32.1	32.1	32.0	32.3	32.4
	Ox (mg/L)	7.3	7.4	7.3	6.8	7.0	6.5	7.3	7.7	6.9	7.0
	Back (ftu)	3.8	3.9	4.1	4.2	4.8	3.6	3.6	3.4	4.4	4.8
Bot	Temp (°C)	16.2	15.8	15.6	16.4	16.7	16.7	16.5	16.6	16.7	16.4
	Cond (S/m)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.2	4.1
	Sal (psu)	32.4	32.6	32.6	32.4	32.2	32.1	32.3	32.2	32.3	32.5
	Ox (mg/L)	7.4	7.5	7.4	7.0	7.1	6.7	7.3	6.8	7.0	7.1
	Back (ftu)	3.9	4.7	4.7	4.8	6.0	3.4	3.6	3.5	4.8	5.3

Note [1]: Sfc, Mid, and Bot refer to average values measured for the top, middle, and bottom 1/3 of depths sampled at a site, respectively
Note [2]: Temp = Temperature, Cond = Conductivity, Sal = Salinity, Ox = Oxygen, Back = Turbidity

Table 2-6. Summary of physical water quality parameters for Delta sites on the sand mining cruise during August 25-26, 2008

Depth Group[1]	Analyte[2]	D-7781E-01	D-7781E-02	D-7781E-03	D-7781E-04	D-7781E-05	D-7781W-01	D-7781W-02	D-DCMG-03	D-DCMG-04	D-DCMG-05	D-DCSM-01	D-DCSM-02	D-MS-01	D-MS-02	D-MS-03
Sfc	Temp (°C)	21.4	21.3	21.3	21.3	21.7	21.3	21.3	21.2	21.0	21.3	21.2	21.1	21.2	21.2	21.1
	Cond (S/m)	0.6	0.6	0.5	0.5	0.4	1.2	1.2	1.4	1.3	1.2	0.3	0.3	1.2	1.3	1.3
	Sal (psu)	3.8	3.3	2.8	2.9	2.5	7.5	7.8	8.8	8.5	7.3	1.9	2.0	7.3	8.2	7.8
	Ox (mg/L)	9.2	9.6	9.7	9.6	10.2	7.3	7.4	6.6	6.8	7.3	9.7	9.4	7.0	7.6	7.7
	Back (ftu)	9.0	6.4	7.4	9.1	7.2	7.6	7.1	7.4	6.7	8.0	8.4	8.8	6.7	7.0	7.6
Mid	Temp (°C)	21.3	21.2	21.2	21.2	21.8	21.1	21.1	21.1	21.1	21.0	21.2	21.1	21.1	21.1	21.0
	Cond (S/m)	0.7	0.6	0.5	0.5	0.4	1.3	1.3	1.5	1.4	1.3	0.3	0.3	1.4	1.5	1.4
	Sal (psu)	4.2	3.6	3.0	3.1	2.6	8.1	8.3	9.7	9.1	8.3	2.0	2.0	9.0	9.5	9.2
	Ox (mg/L)	8.6	10.0	8.7	8.1	11.3	7.4	7.4	7.0	7.0	7.3	11.3	9.0	7.2	7.5	7.7
	Back (ftu)	6.1	7.0	8.7	9.9	8.1	7.5	8.5	14.3	11.5	10.0	8.5	8.9	9.8	9.9	12.8
Bot	Temp (°C)	21.2	21.2	21.2	21.2	21.8	21.0	21.1	21.1	21.1	21.1	21.2	21.1	21.0	21.0	21.1
	Cond (S/m)	0.7	0.7	0.6	0.6	0.4	1.4	1.4	1.6	1.4	1.3	0.3	0.3	1.5	1.5	1.5
	Sal (psu)	4.4	4.0	3.5	3.3	2.6	8.6	8.6	9.9	9.2	8.3	2.0	2.0	9.4	9.5	9.3
	Ox (mg/L)	7.5	7.8	7.9	7.7	12.2	7.4	7.4	7.2	7.1	7.4	9.2	8.1	7.3	7.5	7.7
	Back (ftu)	9.0	7.8	8.9	10.2	8.6	9.7	10.1	16.0	13.5	12.2	8.5	8.8	14.0	11.7	14.7

Note [1]: Sfc, Mid, and Bot refer to average values measured for the top, middle, and bottom 1/3 of depths sampled at a site, respectively
Note [2]: Temp = Temperature, Cond = Conductivity, Sal = Salinity, Ox = Oxygen, Back = Turbidity

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With the dividing plate inserted and held in place, the subsample for grain size and TOC was removed from the grab. After this, all sediment material on that half of the grab was removed with spoons or by hand, ensuring that the dividing plate remained in position. After all sediment material was removed from the first subsample, the dividing plate was removed, the grab jaws were opened, and the remaining subsample was washed from the grab into a plastic tub for processing of infauna.

All collected sediment was washed through a 2.0 mm screen to capture any large bivalves, worms, gastropods and other large benthic organisms, as well as remove any shell fragments, or other large debris. Organisms captured on the 2.0 mm screen were placed into the 1.0 mm-labeled sample jar. Infauna subsamples were transferred to an infauna-processing chamber that gently washed and lifted coarse sediments, allowing benthic infauna to rise to the water surface and float through a sluice gate into nestled 1.0 and 0.5 mm nylon mesh bags. The nested 0.5 and 1.0 mm mesh bags were placed into a full bucket of water while samples were being processed, to prevent impingement of organisms on the nets. After the sediment in the infauna-processing chamber was sufficiently washed to float all visible organisms, the remaining sand was also carefully washed into a labeled 2-gallon bucket and preserved with 70% isopropyl alcohol and Rose Bengal stain. Any organisms observed in the sand were carefully removed to the 1.0 mm jar.

At the conclusion of processing a sample, the nested nylon bags were removed and the contents of the 0.5 and 1.0 mm bags were carefully washed and transferred onto separate 0.5 mm sieves for further screening, prior to placement into labeled sample jars. Once each sample was washed through the screen, the material (debris, coarse sediment, and organisms) retained on the screen was transferred to a sample container. All sample containers were labeled with an external label containing the station name, sample ID, date, time, and "split number" (*i.e.,* 1 of 1, 2 of 3, etc.) if required. A label bearing the same information was placed inside the jars containing infaunal samples. The sample containers had a screw-cap closure and were sufficiently large to accommodate the sample material with a head-space of at least 30% of the container volume. Some samples were split among multiple containers. The sample containers were filled to approximately 50 to 70% of capacity with screened material. After the bulk of material had been transferred to the container, any organisms remaining on the screens were removed with forceps and added to the sample container. The screens were washed thoroughly between samples.

All infaunal samples were treated with an isotonic relaxant solution (Epsom salts, $MgSO_4$) for approximately 10-30 minutes prior to fixation to facilitate handling during taxonomic identification. After the relaxant treatment, the relaxant was decanted from the sample through a screen with a mesh size of 0.5 mm or less. Any animals adhering to the screen were carefully removed and placed back in the sample container. The container was then filled with sodium borate-buffered 10% formalin and stored for return to the laboratory. The samples were stored in formalin for no less than 72 hours, after which they were transferred to 70% isopropyl alcohol preservative.

2.1.3 Sediment Chemistry Samples

For sediment grain size analysis, approximately 100 g of sediment was collected at each station and placed in an 8 oz (250 mL) plastic container, taking care to leave an air space at the top. Samples were stored on wet ice until returned to the laboratory. For TOC analysis, approximately 200 g of sediment was collected at each station and placed in an 8 oz (250 mL) glass container with a Teflon-lined lid. The container was filled 80% full. Samples were stored on wet ice initially, but frozen within 24 hours.

2.2 Analytical Procedures

2.2.1 Benthic Infauna Samples

Upon receipt at the taxonomic lab, each sample was initially decanted of alcohol through a 0.5 mm screen, gently rinsed with water and then washed from the screen into a holding container. A small portion of each sample was spooned into a gridded Petri dish and sorted under 10x power of a dissecting microscope. Removed organisms were placed into pre-labeled vials according to taxonomic group, *i.e.,* Polychaeta (polychaete worms), crustaceans (amphipods, isopods, crabs and other "shellfish"), Mollusca (snails and clams), Oligochaeta (round worms), Polychaete fragments (body pieces without heads), and Other. When multiple containers were required to preserve retained material in the field, all jars from the same station and screen size were combined during the sorting phase.

Each vial was labeled with taxonomic group name, station number, collection date, screen size, and sorter's initials using 100% rag paper or provided labels. Sample debris was placed back into the original sample container using recycled ETOH for preservation. Sorted taxa were then identified to the lowest taxon practicable. Reference specimens were kept for future use and validation, where required.

Ten percent of all samples (minimum one sample) from each sorter were re-sorted by a second sorter to verify quality control. In addition, 10% of the buckets containing field-processed sand collected from each lease grouping (Central Bay, Middle Ground Shoal, Suisun Marsh) were carefully viewed under a microscope to determine if any organisms remained within the processed sand. Five buckets of sand were reprocessed in the lab and >97% of all collected organisms were removed from the sand and placed into sample jars in the field.

2.2.2 Sediment Chemistry Samples

Columbia Analytical in Kelso, WA analyzed sediment particle size and TOC. Particle size determinations were performed according to ASTM method D422 Modified, providing size categories of medium gravel, fine gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand, silt and clay. TOC was analyzed according to ASTM method D4129-82M.

2.2.3 Statistical Procedures

Several statistical procedures were used to analyze biological and chemistry data in order to:

- Characterize the benthic habitats and biological communities,
- Contrast them between mined and unmined areas,
- Describe physical factors responsible for differences in benthic communities, and
- Examine recovery of benthic communities following mining.

Descriptive, agglomerative and parametric statistical procedures were applied sequentially to examine the data for broad patterns and then to determine the causes for those patterns. Agglomerative and parametric procedures were performed with JMP statistical software (SAS Institute 2000). First, the data were tabulated and examined for obvious patterns that might guide the following statistical procedures. Second, the biological data were used to produce site clusters using Ward's minimum variance method, in which the distance between two clusters is the analysis of variance (ANOVA) sum of squares between the two clusters added up over all the variables. The software was allowed to define clusters using the default algorithm that delineates clusters based upon the inflection point in the curve describing the distance between successive cluster nodes. Third, ANOVA was performed to test for differences in benthic organisms among the identified clusters and between sites in leases and control sites. To minimize effects of rare species, only taxa that were both common (*i.e.,* found in >15% of samples) and abundant (*i.e.,* constituted >0.15% of total abundances across all sites) were used in statistical procedures.

Because portions of an individual mining lease may not have been mined due to operational limitations, and because variation in the elapsed time since the last mining event could compromise comparisons between leased and control sites, mining records of the lease operator were checked to obtain information on what locations had been mined within the past several years. This information allowed further categorization of sites according to their probable recent mining history into: (1) sites that were known to have been mined, (2) sites that possibly could have been mined and, (3) sites that were known to not have been mined in the previous 36 months. These three site categories also were the basis for ANOVA tests of organism densities. Where significant differences were detected by the ANOVAs, the Tukey *a posteriori* test was performed to determine between which clusters or site groups there were differences.

Finally, stepwise linear regressions were performed to determine whether spatial patterns of benthic organism abundances (dependent variable) were associated with physical variables, such as site depth, sediment grain size and months since dredging (independent variables). Sites for which the last mining date was not available were assigned a value of 60 months for sites that most likely had not been mined, and 36 months for sites that possibly had been mined in the last 3 years. These tests enabled determination of which independent variables are significantly correlated with the dependent variable when the effects of all other independent variables are considered. That is, they remove the effects of covariation among independent variables. For example, bivariate correlations that appear to be positive might actually be negative when the effects of all other variables are taken into account. All independent variables were entered into each model and those that were not significant ($p > 0.05$) were removed in a stepwise fashion until only significant variables remained. Because of the high number of statistical analyses performed, the probability of detecting significant regression models due to chance alone was reduced by considering only those with a probability of <0.005. Lastly, in order to determine which of the significant independent variables contributed most to the variation in organism densities, partial regressions were calculated between each dependent variable and its significant independent variables. This procedure calculates the correlation between pairs of variables, while removing the effects of all other variables.

3 Data Results

3.1 Central Bay

3.1.1 Characterization of Central Bay Benthic Habitats and Biological Communities

From the twenty five samples collected from the nine Central Bay mining leases and two control areas, a total of 107 taxa were identified. Benthic communities were numerically dominated by nematoda, followed by polychaetea, amphipoda, and bivalvia (Table 3-1), which averaged 884, 484, 269 and 185 animals/m^2, respectively. Total organism densities averaged nearly 2,000/m^2.

There were large differences among Central Bay sites in the numbers of taxa (species richness), numbers of organisms (total abundance), and sediment characteristics (Table 3-1 and Table 3-2). For example, two sites, 7779W-02 and 7779W-04, had greater than 39 taxa and 4,000 organisms/m^2, while Site 2036-01 also had greater than 4,000 organisms/m^2 but had only 25 taxa. In contrast, site 7780N-01 had only 307 organisms/m^2 and 10 taxa and site 709N-03 had only 343 organisms/m^2 and 7 taxa. Sites 2036-01, 7779W-01, 7779W-02 and 7779W-04 also had coarser sediments than did other sites, with 25.6%, 27.1%, 34.1% and 48.7% medium gravel, respectively.

Samples from 7779W-01, 7779W-02, 7779W-03, 7779W-04 and 2036-01 all contained substantial gravel (Table 3-1). Samples from 2036-02, 77779-02, CBCN-01, CBCS-02, 709E-01, and 7780S-02 contained some gravel and shell fragments, shells, or small pebbles (Table 2-3). Many of the larger shell fragments and pebbles had encrusting organisms attached, including live barnacles (Cirripedia), hydroids and bryozoans. Epifaunal taxa were noted primarily at those sites with high gravel content.

Multivariate statistical clustering of all sites in Central Bay, based upon the abundances of dominant taxa, revealed five groupings. These five groupings did not correspond to individual leases or control sites (Table 3-1 and Figure 3-1). As illustrated in Figure 3-1, Clusters 1, 2, and 3 consisted of 5, 5 and 12 sites respectively and had one or more control sites combined with mining lease sites. Clusters 4 and 5 did not contain any control sites and consisted of one site and two sites, respectively.

The five clusters differed in their average taxa abundances, or number of individuals per area (density) (Figure 3-2). Clusters 1 and 2 differed from the other clusters due to their dominance by nematoda. Cluster 3 exhibited lower densities of nematodes than observed in Clusters 1 and 2 and did not exhibit dominance by any one taxon, with nematoda and the polychaete *Heteropodarke heteromorhpha* exhibiting similar densities. Cluster 4 was dominated by the bivalve *Nutricola* spp. Cluster 5 had high densities of the amphipod *Photis* spp., the polychaete *Capitella capitata* (complex), and the amphipods *Gnathopleustes pugettensis* and *Megamoera subtener*. Additionally, a second tier of taxa in Cluster 5 includes nematoda, the bivalves *Nutricola* and Mactridae unident., the polychaetes *Glycinde* spp., *Armandia brevis*, and *Glycera* spp., as well as oligochaetes, and the holothuroid *Leptosynapta* spp.

Analysis of Variance (ANOVA) tests confirmed differences among the five clusters based on the same 15 most abundant taxa (Table 3-3). Nematoda densities were significantly greater in Cluster 1 and Cluster 2 than in any of the other clusters, with Cluster 1 having greater nematode densities that Cluster 2. Densities of the bivalve *Nutricola* spp. were greater in clusters 4 and 5 than in any of the other clusters with Cluster 4 having greater *Nutricola* spp. densities than Cluster 5. Densities of the amphipods *Photis* spp. and *Megamoera subtener*, the polychaete *Capitella capitata* (complex) and Mactridae bivalves were all greater in Cluster 5 than in any of the other clusters. The holothuroid *Leptosynapta* spp. had greater densities in Cluster 5 than in clusters 1, 2 or 3. Finally, total amphipods, total numbers of organisms and total numbers of taxa were greater in Cluster 5 than in any of the other clusters, whereas total bivalves were greater in Cluster 4 than in Clusters 1, 2, 3, and 5.

Slight differences in water depth or grain size could account for some of the observed differences in taxa densities in the five clusters (Table 3-4). ANOVA and Tukey's tests revealed that Cluster 5 was slightly deeper than Cluster 3 and had a greater percentage of medium gravel than any of the other clusters. There was no difference among clusters in the estimated months since mining.

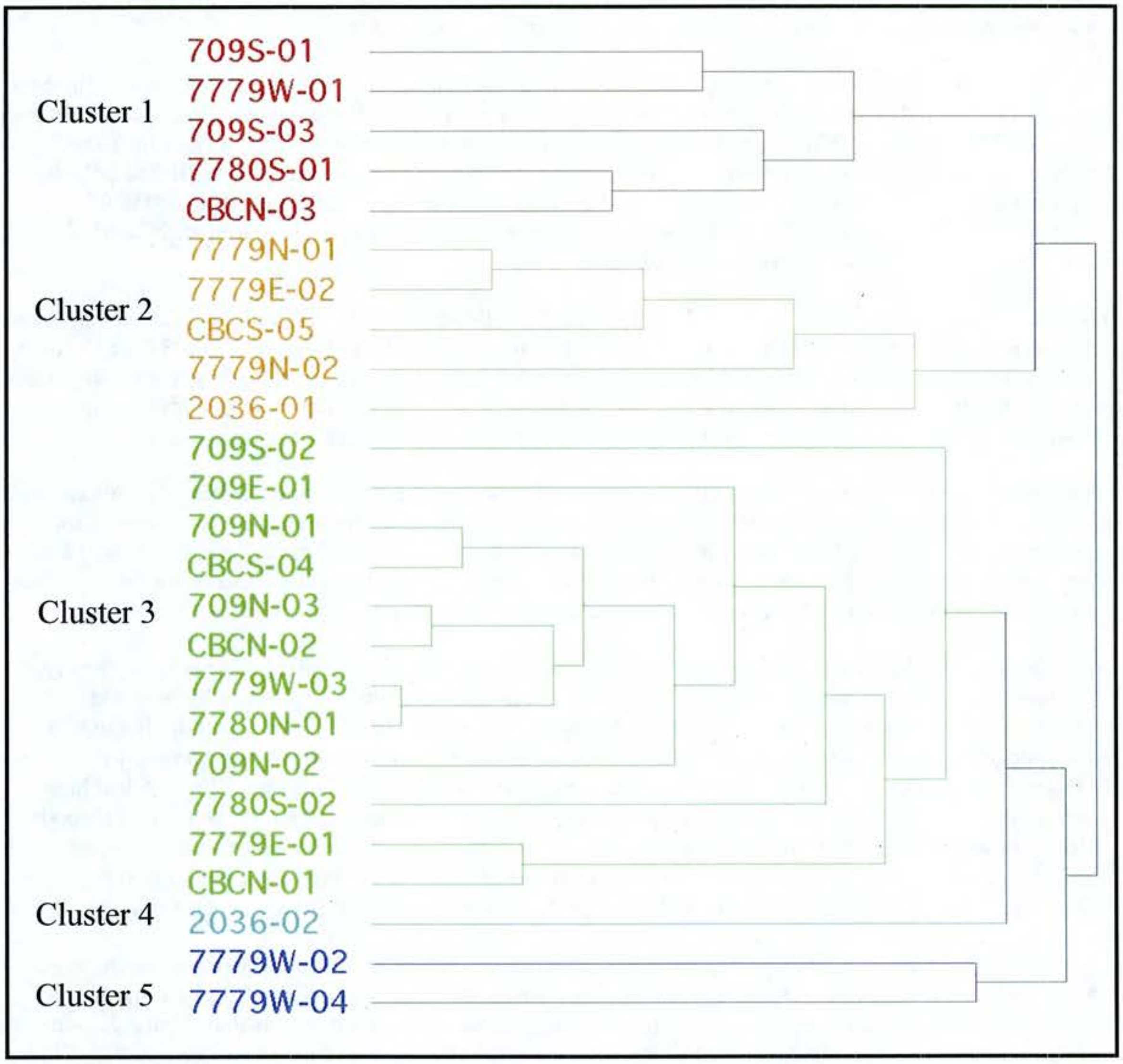

Figure 3-1. Multivariate statistical clusters (Ward's minimum variance method) of Central Bay sites, based upon abundances of common or abundant taxa

Table 3-1. Organism densities and numbers of taxa collected in benthic samples from Central Bay

[illegible]

Table 3-2. Depths and sediment characteristics of samples collected in Central Bay

Physical factor	709N-01	709N-02	709N-03	709E-01	709S-01	709S-02	709S-03	7779N-01	7779N-02	7779E-01	7779E-02
Sample depth, MLLW, corrected (m)	15.6	19.0	16.7	19.6	26.4	23.0	17.8	25.5	30.3	23.9	20.1
TOC (%)	0.15	0.22	0.20	0.14	0.73	0.27	0.09	0.16	0.21	0.08	0.08
Gravel, Medium (%)	0.58	1.31	0.74	2.00	0.00	1.13	0.00	0.00	0.10	0.00	3.72
Gravel, Fine (%)	2.71	5.55	4.60	2.20	0.00	1.84	0.03	1.29	0.59	0.11	0.34
Sand, Very Coarse (%)	10.20	14.30	19.50	10.80	0.05	1.22	0.11	4.28	7.50	0.55	1.08
Sand, Coarse (%)	17.30	25.30	35.80	28.50	0.29	0.78	1.75	14.00	14.80	9.18	11.00
Sand, Medium (%)	18.40	54.60	26.10	42.80	13.90	6.28	31.60	57.50	40.50	61.80	56.60
Sand, Fine (%)	50.80	0.28	13.40	12.50	86.60	65.51	59.70	17.20	26.70	29.10	25.60
Sand, Very Fine (%)	0.59	0.06	0.04	0.04	0.41	1.47	0.46	0.15	0.13	0.06	0.08
Silt (%)	1.41	0.63	0.07	0.12	6.30	15.80	0.45	3.46	0.30	0.08	0.05
Clay (%)	2.28	1.75	0.94	0.98	0.57	2.71	1.05	4.99	1.25	1.14	0.84
Mining Status	No	Possible	Possible	No	Yes	Yes	Yes	No	No	Possible	No
Estimated months since last mining	60	36	36	60	6	19	14	60	60	36	60

Site

Physical factor	7779W-01	7779W-02	7779W-03	7779W-04	7780N-01	7780S-01	7780S-02	2036-01	2036-02	CBCN-01	CBCN-02	CBCN-03	CBCS-04	CBCS-05
Sample depth, MLLW, corrected (m)	26.2	26.4	29.7	40.2	22.7	23.4	24.5	24.2	23.1	14.5	18.3	20.7	21.4	22.4
TOC (%)	0.16	0.09	0.11	0.19	1.01	0.16	0.16	0.10	0.20	0.14	0.21	0.33	0.63	0.23
Gravel, Medium (%)	27.10	34.10	16.50	48.70	3.93	1.20	0.00	25.60	6.66	0.49	0.00	0.00	0.09	0.92
Gravel, Fine (%)	17.10	18.60	27.20	15.80	6.02	1.11	0.44	15.00	3.02	1.43	0.18	0.13	0.25	0.54
Sand, Very Coarse (%)	10.80	14.60	23.40	6.99	34.90	2.03	1.20	27.70	7.83	7.80	1.07	0.94	0.62	0.01
Sand, Coarse (%)	18.30	12.40	23.10	9.00	17.70	21.14	24.10	15.90	11.30	15.90	7.79	5.92	11.30	11.80
Sand, Medium (%)	13.90	12.80	8.54	14.40	12.30	50.80	53.50	6.04	25.70	29.60	49.50	50.69	72.00	56.90
Sand, Fine (%)	16.10	8.09	3.46	6.86	18.60	22.90	19.14	9.19	43.90	45.40	38.90	42.92	15.90	26.70
Sand, Very Fine (%)	0.21	0.07	0.03	0.10	0.07	0.08	0.06	0.07	0.38	0.21	0.13	0.12	0.04	0.13
Silt (%)	0.28	0.32	0.03	0.71	2.20	0.04	0.25	0.18	1.77	0.47	0.21	0.16	0.03	1.25
Clay (%)	0.57	0.59	0.32	1.24	3.37	0.81	0.88	0.55	2.65	1.14	1.10	1.22	1.13	1.58
Mining Status	Yes	No	Yes	No	Possible	No	Possible	Yes	Yes	No	No	No	No	No
Estimated months since last mining	19	60	11	60	36	60	36	13	4	60	60	60	60	60

= Cluster 1
= Cluster 2
= Cluster 3
= Cluster 4
= Cluster 5

Table 3-3. ANOVA results for differences in abundances of the 15 most abundant taxa among Central Bay clusters

Taxon[1] or Group	Group	r^2	p	Tukey Results[2]
Nematoda	Nematoda	0.9554	<0.0001	1>2>3=5=4
Heteropordarke heteromorpha	Polychaeta	0.0816	0.7750	3=2=1=5=4
Photis spp.	Amphipoda	0.9445	<0.0001	5>4=1=3=2
Nutricola spp.	Bivalvia	0.9955	<0.0001	4>5>3=1=2
Capitella capitata (complex)	Polychaeta	0.4778	0.0087	5>1=2=3=4
Glycinde spp.	Polychaeta	0.0716	0.8165	5=4=3=1=2
Gnathopleustes pugettensis	Amphipoda	0.5096	0.0049	5=4, 5>2=3=1, 4=2=3=1
Oligochaeta	Oligochaeta	0.1410	0.5272	2=5=1=3=4
Armandia brevis	Polychaeta	0.3808	0.0398	5=1=2=4, 5>3, 1=2=3=4
Glycera spp.	Polychaeta	0.1707	0.4165	5=1=3=2=4
Megamoera subtener	Amphipoda	0.9775	<0.0001	5>2=4=3=1
Mediomastus spp.	Polychaeta	0.1175	0.6230	2=3=1=4=5
Ampelisca abdita	Amphipoda	0.0433	0.9205	3=2=1=4=5
Mactridae	Bivalvia	0.8027	<0.0001	5>4=1=2=3
Leptosynapta spp.	Holothuria	0.4993	0.0059	5=4, 5>2=1=3, 2=1=3=4
Total Polychaeta	Polychaeta	0.2343	0.2316	5=2=3=1=4
Total Amphipoda	Amphipoda	0.9172	<0.0001	5>3=4=2=1
Total Bivalvia	Bivalvia	0.9591	<0.0001	4>5>3=1=2
Total Number or Organisms	-	0.7626	<0.0001	5>3, 5>1=2, 5=4, 1=4=2, 4=2=3
Total Number of Taxa	-	0.7663	<0.0001	5>4=1=2=3

Note [1]: Taxa listed in order of overall average densities
Note [2]: Highest mean density is on the left and lowest is on the right

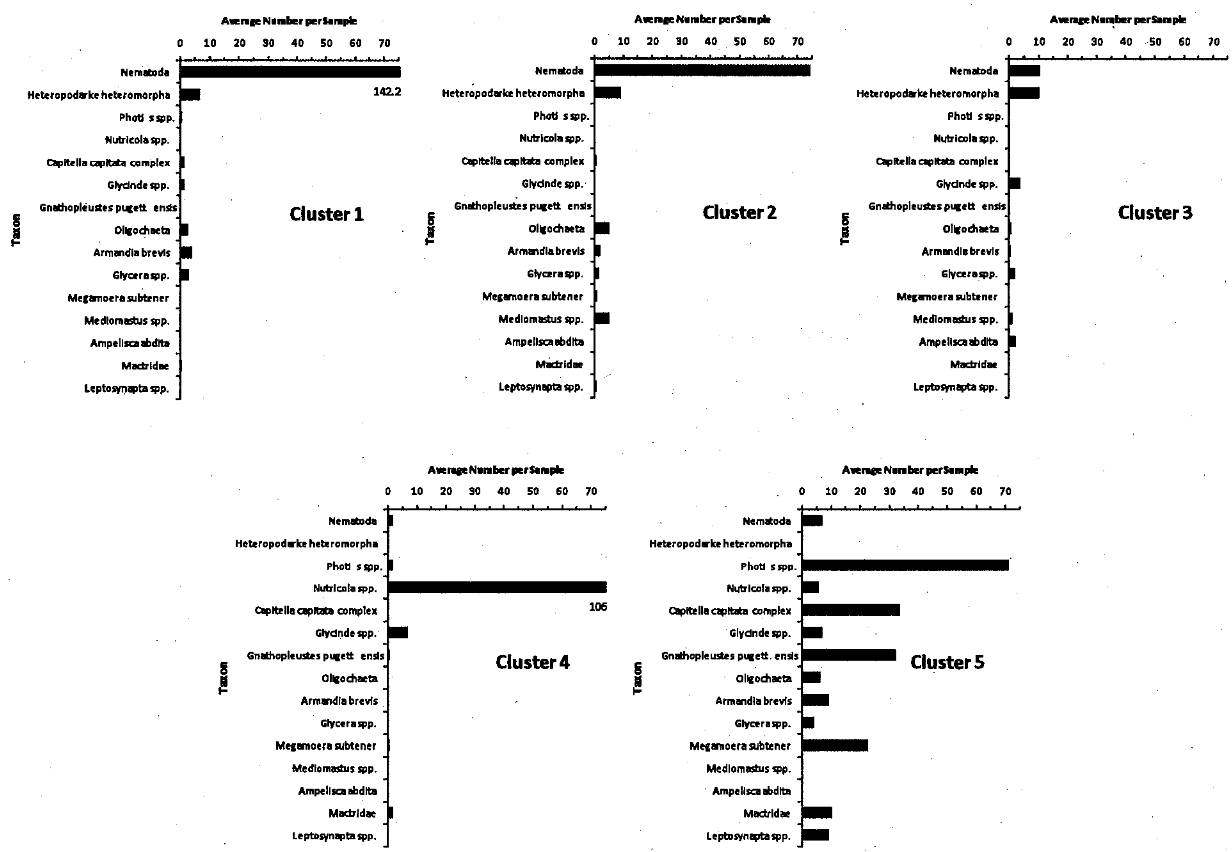

Figure 3-2. Densities of the 15 most abundant benthic taxa in five clusters identified for Central Bay sites

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Table 3-4. ANOVA results for differences in physical factors among Central Bay clusters

Factor	(r^2)	(p)	Tukey Results[1]
Months since mining	0.2334	0.2337	5=2=3=4=1
Depth	0.4056	0.0278	5>3, 5=2=1=4, 2=1=4=3
% Total Organic Carbon	0.0736	0.8081	1=3=4=2=5
% Medium Gravel	0.6525	0.0002	5>4=2=1=3
% Fine Gravel	0.2446	0.2085	5=3=1=2=4
% Very Coarse Sand	0.1065	0.6698	5=3=2=4=1
% Coarse Sand	0.1590	0.4583	3=2=4=5=1
% Medium Sand	0.1398	0.5321	2=3=1=4=5
% Fine Sand	0.2456	0.2064	1=4=3=2=1
% Very Fine Sand	0.0580	0.8695	4=1=3=2=5
% Silt	0.0161	0.9871	3=4=7=2=5
% Clay	0.1781	0.3913	4=2=3=5=1

Note [1]: Highest mean value is on the left and lowest is on the right

3.1.2 Effects of Sand Mining on Central Bay Bottom Sediments and Benthic Communities

Although the clustering of both leased and control sites (e.g., Clusters 1, 2 and 3) suggests that sand mining does not appear to exert a strong influence on Central Bay benthic communities sampled in the mining leases, additional statistical tests were performed to (1) further examine this possibility, (2) determine whether sand mining is associated with differences in sediment grain size, and (3) to help determine the factors associated with differences in taxa densities. ANOVA and Tukey's tests were performed to test for differences in organism abundances and sediment characteristics between samples collected in leased areas and those from control sites, as well as among sites known to have been mined in the last 36 months, those that might have been mined within the last 36 months and those that were not mined within the last 36 months.

There were no significant differences between leased and control sites or among sites that had been, had not been, or had possibly been mined in the previous 36 months, for the most common and abundant taxa, total polychaetes, total amphipods, total bivalves, number of organisms or total number of taxa (Table 3-5 and Table 3-6).

Despite the absence of detectable mining effects on benthic community structure, there are indications that sand mining has affected the grain size at leased locations. ANOVA performed to test for differences in grain size and total organic carbon revealed that sites on mining leases had significantly less medium sand than did control sites, and this difference could not be accounted for by differences in depth (Table 3-7). Moreover, sites known to have been mined in the previous 36 months had significantly less medium sand and significantly more very fine sand than did sites that had either not been mined or possibly were mined (Table 3-8). All these differences are consistent with the removal of medium and coarse sand by sand mining operations.

It is possible that the absence of statistically significant effects on benthic organism densities associated with either being in a lease or assumed recent antecedent mining activity could be due to uncontrolled confounding factors. For example, if lease areas contain either sites that have never been mined or biological communities in different stages of recolonization as a result of mining or other physical disturbances, the accompanying higher among-sample variation could make it difficult to detect differences between leased and control sites. The same potential problems apply to statistical comparisons of sites that have been mined, possibly have been mined, and never have been mined. To evaluate this possibility, stepwise linear regressions were performed to investigate whether any combination of months since mining, sediment grain size, sediment organic content (total organic carbon), and site water depth could account for spatial patterns in organism densities of 17 taxa, total polychaetes, total bivalves, total amphipods, total number of taxa and total number of organisms.

Depth, sediment grain size, total organic carbon and months since mining each were associated with spatial patterns in some benthic taxa, the total number of polychaetes, total number of amphipods, total number of organisms and the total number of taxa (Table 3-9). Various categories of sediment grain size were most often the significant variables associated with these spatial patterns. Months since mining was a significant variable for the amphipod *Megamoera subtener*, the polychaete *Nephtys ?californiensis*, and total amphipods, with the number of individuals being greater with increasing time since mining, in each case. This suggests a negative effect of mining on these organisms, since the number of individuals appears to increase with time following a mining event.

In order to determine which significant variables from the linear regression analyses had the greatest potential effects on organism densities, partial correlations were calculated and presented for the three most important variables for each taxon, as appropriate. The partial correlations are not related to the numerical multipliers associated with each significant independent variable in Table 3-9, which vary according to the magnitude of the dependent variable being modeled and the magnitude of the units in which each independent variable is measured. These partial correlations revealed that various categories of sediment grain size predominated among the three most important variables for each taxon or group that exhibited a significant regression model (Table 3-10). Only three exceptions to this characterization occurred; the bivalve *Clinocardium nuttalllii*, the polychaete *Nephtys ?californiensis* and opheliid polychaetes each had at least one of their three most important variables that was not a sediment grain size. Moreover, neither of the two significant variables for *N. ?californiensis* was a category of sediment grain size.

Categories of sediment grain size were the most important variables for explaining spatial patterns in organism densities for all but one taxon with significant linear regressions (Table 3-10), with only the polychaete *Nephtys ?californiensis* having a most important independent variable that was something other than sediment grain size (*i.e.*, site depth). Of those taxa with a category of sediment grain size as the most important variable, the effects of medium gravel predominated. Positive correlations with medium gravel were most important for the amphipod *Photis* spp., oligochaeta, mactridae bivalves, the holothurian *Leptosynapta* spp., the isopod *Synidotea consolidata*, the bivalve *Clinocardium nuttallii*, the polychaetes *Malmgreniella* spp. and *Chone* spp., total polychaetes and the total number of taxa. Fine gravel was the most important variable for the amphipod *Monocorophium* spp. Positive correlations with fine sand, very fine sand or silt were most important for four taxa (*i.e.*, the amphipod *Ampelisca abdita*, nemertea, unidentified opheliid polychaetes and unidentified phoxicephaliid amphipods). Negative correlations with medium or fine sand were most important for three taxa (the polychaete *Glycinde* spp. and *Armandia brevis*, and the amphipod *Megamoera subtener*), as well as for total amphipods and the total number of organisms.

The second and third most important variables for explaining spatial patterns in organism densities also were dominated by categories of sediment grain size, with only three taxa having something other than sediment grain size as a second or third most important variable (Table 3-10). Months since mining and site depth were the second and third most important variables for *Nephtys ?californiensis* and

Table 3-5. ANOVA results for differences in organism abundances between leased and control sites in the Central Bay

Taxon[1] or Group	Group	(r^2)	(p)	Tukey Results[2]
Nematoda	Nematoda	0.0021	0.8267	Control=Leased
Heteropordarke heteromorpha	Polychaeta	0.0664	0.2136	Control=Leased
Photis spp.	Amphipoda	0.0224	0.4747	Leased=Control
Nutricola spp.	Bivalvia	0.0146	0.5656	Leased=Control
Capitella capitata (complex)	Polychaeta	0.0160	0.5464	Leased=Control
Glycinde spp.	Polychaeta	0.0267	0.4348	Leased=Control
Gnathopleustes pugettensis	Amphipoda	0.0118	0.6048	Leased=Control
Oligochaeta	Oligochaeta	0.0397	0.3397	Leased=Control
Armandia brevis	Polychaeta	0.0596	0.2397	Leased=Control
Glycera spp.	Polychaeta	0.0152	0.5565	Control=Leased
Megamoera subtener	Amphipoda	0.0277	0.4269	Leased=Control
Mediomastus spp.	Polychaeta	0.0241	0.4585	Leased=Control
Ampelisca abdita	Amphipoda	0.0127	0.5914	Leased=Control
Mactridae	Bivalvia	0.0297	0.4104	Leased=Control
Leptosynapta spp.	Holothuroidea	0.0001	0.9570	Leased=Control
Hesionura coineaui difficilis	Polychaeta	0.0024	0.8173	Leased=Control
Synidotea consolidata	Isopoda	0.0094	0.6450	Leased=Control
Nemertea	Nemertea	0.0221	0.4780	Leased=Control
Modiolus rectus	Bivalvia	0.0225	0.4737	Leased=Control
Tellina nuculoides	Bivalvia	0.0667	0.2128	Leased=Control
Foxiphalus obtusidens	Amphipoda	0.0068	0.6943	Leased=Control
Lamprops quadriplicata	Cumacea	0.0196	0.5048	Control=Leased
Clinocardium nuttallii	Bivalvia	0.0179	0.5232	Leased=Control
Malmgreniella spp.	Polychaeta	0.0463	0.3019	Leased=Control
Pisione spp.	Polychaeta	0.0384	0.3475	Leased=Control
Nephtys ?californiensis	Polychaeta	0.0376	0.3532	Leased=Control
Opheliidae unidentified	Polychaeta	0.0549	0.2597	Leased=Control
Chone spp.	Polychaeta	0.0341	0.3769	Leased=Control
Nephtys caecoides	Polychaeta	0.0030	0.7956	Control=Leased
Monocorophium spp.	Amphipoda	0.0299	0.4089	Leased=Control
Phoxicephalidae unidentified	Amphipoda	0.0476	0.2947	Leased=Control
Total Polychaeta	Polychaeta	0.0190	0.5113	Leased=Control
Total Amphipoda	Amphipoda	0.0364	0.3610	Leased=Control
Total Bivalvia	Bivalvia	0.0389	0.3446	Leased=Control
Total Number of Organisms	-	0.0353	0.3684	Leased=Control
Total Number of Taxa	-	0.0570	0.2506	Leased=Control

Note [1]: Taxa listed in order of overall average densities
Note [2]: Highest mean density is on the left and lowest is on the right

Table 3-6. ANOVA results for differences in organism abundances among Central Bay sample sites that were mined, possibly mined, and not mined in the previous 36 months

Taxon[1] or Group	Group	(r^2)	(p)	Tukey Results[2]
Nematoda	Nematoda	0.1780	0.1158	Yes=No=Possible
Heteropordarke heteromorpha	Polychaeta	0.0466	0.5917	Possible=No=Yes
Photis spp.	Amphipoda	0.0718	0.4404	No=Yes=Possible
Nutricola spp.	Bivalvia	0.1012	0.3091	Yes=No=Possible
Capitella capitata (complex)	Polychaeta	0.0278	0.7333	No=Yes=Possible
Glycinde spp.	Polychaeta	0.1491	0.1693	Yes=No=Possible
Gnathopleustes pugettensis	Amphipoda	0.0385	0.6495	No=Yes=Possible
Oligochaeta	Oligochaeta	0.1691	0.1304	Yes=No=Possible
Armandia brevis	Polychaeta	0.1486	0.1705	Yes=No=Possible
Glycera spp.	Polychaeta	0.1150	0.2610	No=Possible=Yes
Megamoera subtener	Amphipoda	0.0611	0.4998	No=Yes=Possible
Mediomastus spp.	Polychaeta	0.1665	0.1349	Yes=Possible=No
Ampelisca abdita	Amphipoda	0.0992	0.3168	Yes=No=Possible
Mactridae	Bivalvia	0.0403	0.6361	No=Yes=Possible
Leptosynapta spp.	Holothuroidea	0.0519	0.5562	No=Possible=Yes
Hesionura coineaui difficilis	Polychaeta	0.0963	0.3282	Yes=No=Possible
Synidotea consolidata	Isopoda	0.0542	0.5419	No=Possible=Yes
Nemertea	Nemertea	0.0716	0.4417	Yes=No=Possible
Modiolus rectus	Bivalvia	0.0548	0.5383	No=Possible=Yes
Tellina nuculoides	Bivalvia	0.0325	0.6950	Possible=Yes=No
Foxiphalus obtusidens	Amphipoda	0.1631	0.1411	Possible=No=Yes
Lamprops quadriplicata	Cumacea	0.0761	0.4186	Yes=No=Possible
Clinocardium nuttallii	Bivalvia	0.0312	0.7056	No=Yes=Possible
Malmgreniella spp.	Polychaeta	0.0159	0.8387	Yes=No=Possible
Pisione spp.	Polychaeta	0.0299	0.7159	Possible=Yes=No
Nephtys ?californiensis	Polychaeta	0.0774	0.4123	No=Possible=Yes
Opheliidae unidentified	Polychaeta	0.1758	0.1192	Yes=No=Possible
Chone spp.	Polychaeta	0.0127	0.8693	No=Possible=Yes
Nephtys caecoides	Polychaeta	0.0751	0.4237	No=Possible=Yes
Monocorophium spp.	Amphipoda	0.1348	0.2033	Yes=No=Possible
Phoxicephalidae unidentified	Amphipoda	0.0620	0.4945	Yes=Possible=No
Total Polychaeta	Polychaeta	0.0623	0.4929	Yes=No=Possible
Total Amphipoda	Amphipoda	0.0367	0.6631	No=Yes=Possible
Total Bivalvia	Bivalvia	0.0928	0.3425	Yes=No=Possible
Total Number of Organisms	-	0.2116	0.0732	Yes=No=Possible
Total Number of Taxa	-	0.0399	0.6392	Yes=No=Possible

Note [1]: Taxa listed in order of overall average densities
Note [2]: Highest mean density is on the left and lowest is on the right

Table 3-7. ANOVA results for differences in physical factors between leased and control sites in the Central Bay

Factor	(r^2)	(p)	Tukey Results[1]
Months Since Mining	0.1882	0.0305	Control>Leased
Depth	0.1152	0.0969	Lease=Control
% Total Organic Carbon	0.0229	0.4702	Control=Leased
% Medium Gravel	0.0679	0.2084	Leased=Control
% Fine Gravel	0.0932	0.1378	Leased=Control
% Very Coarse Sand	0.1178	0.0930	Leased=Control
% Coarse Sand	0.0596	0.2396	Leased=Control
% Medium Sand	0.1753	0.0373	Control>Leased
% Fine Sand	0.0168	0.5366	Control=Leased
% Very Fine Sand	0.0183	0.5199	Leased=Control
% Silt	0.0245	0.4549	Leased=Control
% Clay	0.0081	0.6694	Leased=Control

Note[1]: Highest mean value is on the left and lowest is on the right

Table 3-8. ANOVA results for differences in physical factors among Central Bay sites that were mined, possibly were mined and were not mined in the previous 36 months

Factor	(r^2)	(p)	Tukey Results[1]
Months since mining	0.9023	<0.0001	No>Possible>Yes
Depth	0.0373	0.6586	Yes=No=Possible
% Total Organic Carbon	0.0475	0.5855	Possible=Yes=No
% Medium Gravel	0.0688	0.4563	Yes=No=Possible
% Fine Gravel	0.1262	0.2268	Yes=No=Possible
% Very Coarse Sand	0.1385	0.1940	Possible=Yes=No
% Coarse Sand	0.2412	0.0480	Possible=No, Possible>Yes, No=Yes
% Medium Sand	0.3694	0.0063	No=Possible>Yes
% Fine Sand	0.1696	0.1295	Yes=No=Possible
% Very Fine Sand	0.2394	0.0493	Yes>No=Possible
% Silt	0.1562	0.1544	Yes=No=Possible
% Clay	0.0017	0.8286	Possible=No=Yes

Note[1]: Highest mean value is on the left and lowest is on the right

Clinocardium nuttallii, respectively, whereas site depth was the second most important variable for unidentified opheliid polychaetes. Notably, some taxa whose most important variable was a positive correlation with medium gravel (*i.e.*, the amphipod *Photis* spp., mactridae bivalves, the isopod *Synidotea consolidata*, the bivalve *Clinocardium nuttallii* and the total number of taxa) had negative correlations with fine gravel as their second most important variable. Similarly, the polychaete *Glycinde* spp., the amphipod *Ampelsica abdita* and nemerteans all had converse correlations with either fine sand and very fine sand or with fine or very fine sand and silt among their three most important variables. These results suggest very specific sediment texture requirements for many taxa.

Consequently, while two taxa (*i.e.*, the polychaete *Nephtys ?californiensis* and the amphipod *Megamoera subtener*) and total amphipods had "months since mining" as a significant regression variable (Table 3-9), it was only among the three most important variables for one taxon (*N. ?californiensis*; see Table 3-10) and, because *N. ?californiensis* had only two significant independent variables, it was the least important significant variable for this taxon (Table 3-11).

3.1.3 Assessment for Degraded Benthic Habitats in Central Bay

Recently, a consortium of benthic ecologists who are routinely involved in assessing California benthic communities participated in an evaluation of the use of best professional judgment to assess the environmental conditions associated with benthic communities (Weisberg *et al.* 2008). The study compared the categorization of benthic datasets from throughout California by each ecologist into a range of conditions, from unaffected to severely affected by unspecified perturbations. No chemical data were provided and the ecologists relied on the presence and abundances of certain infaunal species or taxonomic groups to make their assessments. Among the taxa observed in the Central Bay sand mining area, Weisberg *et al.* placed a high value on *Capitella capitata* (complex), oligochaetes, *Mediomastus* spp., *Armandia brevis* and *Monocorophium* spp. as taxa that were tolerant of degraded habitats, and ophiuroids, amphipods and molluscs as taxa were considered sensitive to degraded benthic habitats. Although the evaluation was based on examination of datasets representing a range of organic enrichment and chemical contaminants and may not be as generally applicable to habitats disturbed by physical processes, the results are illustrative of the general condition of benthic habitats in Central Bay.

Taxa observed in the Central Bay sand mining area on which Weisberg *et al.* placed a high value included *Capitella capitata* (complex), oligochaetes, *Mediomastus* spp., *Armandia brevis* and *Monocorophium* spp. These taxa were considered tolerant of degraded benthic habitats, and ophiuroids, amphipods and molluscs as taxa were considered sensitive to degraded benthic habitats.

When these taxa and groups were totaled for the current study, sensitive taxa were more frequently found in higher densities than tolerant taxa (Table 3-12). Organisms in sensitive taxa average 470/m^2 over all sites, with sites 7779W-02 and 7779W-04 (Cluster 5), and Site 2036-02 (Cluster 4) each exceeding 2,200/m^2. Those sites and Site 7780S-02 each had >50% of their total densities contributed by sensitive taxa. Organisms in tolerant taxa averaged 178/m^2, with only sites 2036-01 and 7779W-02 exceeding 1,100/m^2. No sites had >50% tolerant organisms and only Site 7779W-03 had >40% of its total density contributed by tolerant taxa.

Statistical analyses to determine spatial patterns in densities of sensitive and tolerant organisms revealed very few differences between these two groups (Tables 3-13, 3-14, 3-15, and 3-16). Both sensitive and tolerant organisms had their highest densities in Cluster 5 (Table 3-13) and neither differed between leased and control sites (Table 3-14) or between sites that had been mined, probably had not been mined and had not been mined in the 36 months prior to sampling (Table 3-15). Moreover, densities of both sensitive and tolerant organisms were positively correlated with medium gravel (Table 3-16).

Consequently, analyses based on densities of sensitive and tolerant organisms indicate that none of the sites were dominated (*i.e.*, >50%) by organisms tolerant of degraded benthic habitat, and neither group differed between either leased and control or mined and unmined sites. These results suggest that benthic habitats in the Central Bay mining leases would not be considered highly degraded by either organic enrichment or chemical contaminants despite the relatively low overall species richness and organism densities at many of our sampling sites.

Table 3-9. Stepwise linear regression results for highly significant ($p < 0.005$) effects of depth, sediment grain size, total organic carbon and months since mining on organism abundances at Central Bay sites

Taxa[1]	(r^2)	(P)	Regression Model[2]
Photis spp.	0.7795	<0.0001	y = 1.99mgravel – 1.53fgravel – 0.229
Glycinde spp.	0.9514	<0.0001	y = 21.8 + 1.24silt + 14.8vfsand – 0.28depth – 0.27vcsand – 0.18csand – 0.12msand – 0.28fsand
Oligochaeta	0.4762	0.0001	y = 0.33 + 0.30mgravel
Armandia brevis	0.6954	0.0007	y = 36.5 – 0.55fgravel – 0.37vcsand – 0.35csand – 0.39msand – 0.30fsand – 0.68silt
Megamoera subtener	0.7331	<0.0001	y = 24.2 + 0.12months – 0.35vcsand – 0.37csand – 0.30msand– 0.29fsand
Ampelisca abdita	0.9547	<0.0001	y = 6.04 + 11.9vfsand + 1.15silt – 0.11mgravel – 0.12csand – 0.17fsand – 1.06clay
Mactridae	0.8752	<0.0001	y = 0.05 + 0.33mgravel – 0.26fgravel
Leptosynapta spp.	0.6002	<0.0001	y = 0.43 + 0.34mgravel – 0.34fgravel
Synidotea consolidata	0.6870	<0.0001	y = 0.06 + 0.42mgravel – 0.39fgravel
Nemertea	0.9503	<0.0001	y = 10.9 + 0.78silt – 0.09depth – 2.39TOC – 0.58clay – - 0.13fgravel - 0.14csand – 0.05msand – 0.12fsand
Clinocardium nuttallii	0.6913	<0.0001	y = 0.13mgravel + 0.14depth – 0.17fgravel – 2.79
Malmgreniella spp.	0.8353	<0.0001	y = 0.48 + 0.06mgravel + 0.21silt – 0.04vcsand – 0.02fsand
Nephtys ?californiensis	0.5240	0.0003	y = 0.01months + 0.09depth – 2.33
Opheliidae unidentified	0.3663	0.0066	y = 0.04depth + 0.01fsand – 1.14
Chone spp.	0.6480	<0.0001	y = 0.04mgravel – 0.04
Monocorophium spp.	0.5472	0.0002	y = 0.03 + 0.06fgravel – 0.02vcsand
Phoxicephalidae unidentified	0.4399	0.0017	y = 0.02csand + 0.92vfsand – 0.35
Total Polychaeta	0.4249	0.0023	y = 12.4 + 3.10silt + 1.42mgravel
Total Amphipoda	0.7060	0.0001	y = 150 +0.69months – 2.79vcsand – 1.83csand – 1.96msand – 1.59fsand
Total Number of Organisms	0.7630	<0.0001	y = 859 – 10.5fgravel – 10.6vcsand – 7.60csand – 8.34msand – 6.33fsand – 121vfsand
Total Number of Taxa	0.8944	<0.0001	y = 8.89 + 1.40mgravel + 0.98silt – 0.81fgravel

Note [1]: Taxa listed in order of overall average densities
Note [2]: months = (months since last mining), depth = (site water depth), TOC = (total organic carbon), mgravel = (medium gravel), fgravel = (fine gravel), vcsand = (very coarse sand), csand = (coarse sand), msand = (medium sand), fsand = (fine sand), vfsand = (very fine sand)

Table 3-10. The first, second and third most influential independent variables for each Central Bay taxon or group with a highly significant (p <0.005) linear regression, as indicated by their respective partial correlations

Taxa[1]	1st Most Important Variable		2nd Most Important Variable		3rd Most Important Variable	
	Name	Partial Correlation	Name	Partial Correlation	Name	Partial Correlation
Photis spp.	Medium gravel	0.8469	Fine gravel	-0.5765	NA	-
Glycinde spp.	Fine sand	-0.8366	Silt	0.6761	Very fine sand	0.6243
Oligochaeta	Medium gravel	0.6900	NA	-	NA	-
Armandia brevis	Medium sand	-0.7319	Fine sand	-0.6377	Coarse sand	-0.6324
Megamoera subtener	Fine sand	-0.7582	Medium sand	-0.7571	Coarse sand	-0.5635
Ampelisca abdita	Fine sand	0.8012	Silt	-0.8007	Very fine sand	0.7478
Mactridae	Medium gravel	0.9134	Fine gravel	-0.7047	NA	-
Leptosynapta spp.	Medium gravel	0.7522	Fine gravel	0.5534	NA	-
Synidotea consolidata	Medium gravel	0.8026	Fine gravel	-0.5879	NA	-
Nemertea	Silt	0.9602	Fine sand	-0.8596	Coarse sand	-0.7979
Clinocardium nuttallii	Medium gravel	0.6417	Fine gravel	-0.5874	Site depth	0.4780
Malmgreniella spp.	Medium gravel	0.8491	Silt	0.8036	Very coarse sand	-0.5726
Nephtys ?californiensis	Site depth	0.6965	Months since mining	0.4361	NA	-
Opheliidae unidentified	Fine sand	0.5580	Site depth	0.4696	NA	-
Chone spp.	Medium gravel	0.8050	NA	-	NA	-
Monocorophium spp.	Fine gravel	0.7308	Very coarse sand	-0.4136	NA	-
Phoxicephalidae unidentified	Very fine sand	0.6549	Coarse sand	0.5073	NA	-
Total Polychaeta	Medium gravel	0.6209	Silt	0.4077	NA	-
Total Amphipoda	Medium sand	-0.7744	Fine sand	-0.7172	Very coarse sand	-0.5767
Total Number of Organisms	Medium sand	-0.7612	Very coarse sand	-0.7355	Fine sand	-0.7192
Total Number of Taxa	Medium gravel	0.9142	Fine gravel	-0.5990	Silt	0.5663

Note[1]: Taxa listed in order of overall average densities

Table 3-11. Central Bay taxa for which months since mining was a significant variable

Taxa	Partial Correlation with Months Since Mining
Megamoera subtener	0.5408
Nephtys ?californiensis	0.4361[1]
Total Amphipoda	0.5050

Note [1]: Months since mining was the least important significant variable for this

Table 3-12. The numbers and percentages of organisms from Central Bay sites judged to be sensitive or tolerant of degraded benthic habitat by Weisberg *et al.* (2008)

	Number of Organisms per Meter^2																									Overall
Lease-Site	709N-01	709N-02	709N-03	709E-01	709S-01	709S-02	709S-03	7779N-01	7779N-02	7779E-01	7779E-02	7779W-01	7779W-02	7779W-03	7779W-04	7780N-01	7780S-01	7780S-02	2036-01	2036-02	CBCN-01	CBCN-02	CBCN-03	CBCS-04	CBCS-05	Average
# Sensitive Organisms	54	126	54	18	108	1227	36	36	54	0	36	253	3411	18	3249	0	18	505	181	2274	0	36	0	36	18	470
# Tolerant Organisms	54	162	36	0	0	235	253	0	0	0	0	542	1318	90	505	54	0	0	1155	0	18	0	0	0	18	178
% Sensitive Organisms	10.7%	26.9%	15.8%	2.9%	4.3%	40%	1.1%	2.2%	5.3%	0%%	2.6%	7.2%	61.2%	9.1%	58.1%	0%%	0.5%	54.9%	4.%	92.6%	0%	6.9%	0%	7.4%	0.1%	23.8
% Tolerant Organisms	10.7%	34.6%	10.5%	0%	0%	7.6%	7.5%	0%	0%	0%	0%	15.5%	23.6%	45.4%	9.0%	17.6%	0%	0%	25.6%	0%	1.5%	0%	0%	0%	0.1%	9%

= Cluster 1
= Cluster 2
= Cluster 3
= Cluster 4
= Cluster 5

Table 3-13. ANOVA results for differences in physical factors among Central Bay clusters

Factor	(r^2)	(p)	Tukey Results[1]
# Sensitive organisms	0.9368	<0.0001	5>4=3=1=2
# Tolerant organisms	0.4372	0.0171	5>1=3, 5=2=4, 2=1=3=4

Note[1]: Highest mean value is on the left and lowest is on the right

Table 3-14. ANOVA results for differences in organism abundances between leased and control sites in the Central Bay

Factor	(r^2)	(p)	Tukey Results[1]
# Sensitive organisms	0.0544	0.2620	Leased=Control
# Tolerant organisms	0.0607	0.2352	Leased=Control

Note[1]: Highest mean value is on the left and lowest is on the right

Table 3-15. ANOVA results for differences in organism abundances among Central Bay sample sites that were mined, possibly mined, and not mined in the previous 36 months

Factor	(r^2)	(p)	Tukey Results[1]
# Sensitive organisms	0.0295	0.7191	Yes=No=Possible
# Tolerant organisms	0.0822	0.3893	Yes=No=Possible

Note[1]: Highest mean value is on the left and lowest is on the right

Table 3-16. Stepwise linear regressions results for highly significant ($p < 0.005$) effects of depth, sediment grain size, total organic carbon and months since mining on organism abundances at Central Bay sites

Taxa	(r^2)	(P)	Regression Model[1]
# Sensitive organisms	0.5083	<0.0001	y = 90.7 + 54.5mgravel
# Tolerant organisms	0.6820	<0.0001	y = 28.2mgravel – 26.0depth

Note[1]: months = (months since last mining), depth = (site water depth), TOC = (total organic carbon), mgravel = (medium gravel), fgravel = (fine gravel), vcsand = (very coarse sand), csand = (coarse sand), msand = (medium sand), fsand = (fine sand), vfsand = (very fine sand)

3.1.4 Data Interpretation

3.1.4.1 Impact to and Recovery of Central Bay Benthic Communities following Mining

While substantial variation in the composition of benthic assemblages exists among Central Bay sites in leased and control areas, as indicated by Table 3-1 and Figure 3-1, very little of the variation between sites can be attributed to sand mining activities. Clustering of sites based upon abundant and common taxa revealed distinct biological communities, but with a mix of leased and control sites in most clusters. While ANOVA discriminated significant differences among clusters in taxa densities and sediment grain size, none of these biological or grain size differences among clusters were associated with either lease status (samples collected within mining leases versus those collected in control areas) or mining status (sites that had been mined, possibly mined and not mined, in the previous 36 months). The statistical analysis did suggest, however, two possible effects of mining activities. First, significantly reduced percentages of medium sand occurred at sites that had been identified as having been mined in the previous 36 months. Nevertheless, none of the common or abundant taxa with a highly significant regression model exhibited a positive correlation with medium sand, suggesting that this particular grain size does not appear to be a controlling factor for benthic taxa. Second, only two taxa (*i.e.*, the polychaete *Nephtys ?californiensis* and the amphipod *Megamoera subtener*) and total amphipods had densities that significantly correlated with the number of months since mining. Although *N. ?californiensis* was present in samples from only five sites, *Megamoera subtener* was one of the most abundant taxa observed in the Central Bay study area. In all three cases, correlations were positive, indicating increasing densities with increasing time since mining was not the most important variable controlling spatial patterns in any of these cases.

There were no abundance patterns of organisms that are sensitive to or tolerant of degraded benthic habitats that were consistent with mining effects. Neither sensitive nor tolerant organisms varied between leased and control sites or between mined, possibly mined and never mined sites. Moreover, both sensitive and tolerant taxa were positively correlated with medium gravel, which probably indicates more stable benthic habitats at locations with higher gravel sediment content.

Despite a general absence of statistical results showing mining effects, examination of data from individual sites suggests that any damage to benthic communities would be spatially limited, of short duration or obscured by other physical processes. For example, Site 2036-02 was mined within four months of the sampling effort for the current study and had the 7th highest number of taxa and the 9th highest density of organisms of any of the Central Bay sites sampled (Table 3-1). Moreover, the sample from this site was dominated by *Nutricola* spp., a bivalve that would not be expected to recolonize quickly. These results could suggest that the sample was not collected within the specific area of the seafloor that was mined or it could represent unmined seafloor sediments that were located immediately adjacent to the mining trackline that slumped into the excavated trench, transporting resident infauna along with the slumping sand.

Overall species richness and organism densities also did not suggest discernable effects of sand mining. Sample sites that were located along previous sand mining tracks had all been mined within 19 months of our sampling effort (see Tables 3-1 and 3-2) and had a mean organism density of 2,806/m^2, whereas all other sites (*i.e.*, those that possibly had been and those that had not been mined within the previous 36 months) had a mean organism density of 1,654/m^2. These same site groups had a mean number of taxa per sample of 26 and 12, respectively.

3.1.4.2 Comparison with Other Studies

Benthic communities in the area of Central Bay where sand mining occurs have not been well studied. For the past several decades, much of the focus on benthic sampling in San Francisco Bay has been in conjunction with contaminant studies (SFEI 2009). As a consequence, areas of the Bay that posed little risk of chemical contamination of sediments have received little attention. Nevertheless, several studies of benthic communities in San Francisco Bay, or on the effects of aggregate mining on benthic communities, are available for comparison (Newell *et al.* 1998; NOAA 2007; Thompson & Lowe 2004; Thompson *et al.* 2000; Weisberg *et al.* 2008). In a study of aggregate mining in British waters, Newell *et al.* (1998) reported initial recolonization of mined areas by opportunistic species with small body sizes and short life cycles, followed by increases in species richness and abundances of larger, more long-lived equilibrium species. The early colonizers reported by Newell included the polychaete *Capitella capitata* (complex) and the amphipod *Ampelisca abdita* (Table 3-17), both found in our study. Among the forms Newell reported for communities recovering from disturbance are bivalves, which also were well represented in our samples. *C. capitata* (complex), and bivalves both were very abundant in Cluster 5 (Figure 3-2), which was comprised of two sites that have not been mined (Table 3-2), suggesting co-occurrence of early colonizers and equilibrium species. Moreover, as the two sites in Cluster 5 had not been mined, *C. capitata* (complex) abundances in our study are not clearly associated with sand mining disturbance. Densities of *A. abdita* also do not appear to be associated with mining disturbances in our study. Although *A. abdita* did not occur in any of the samples from control sites, and only occurred in three of the 20 mining lease sites, the three sites where it occurred included two sites that had not been mined within the previous 36 months and one site that had been mined within the previous 19 months (Table 3-1 and Table 3-2).

Thompson *et al.* (2000) and NOAA (2007) both reported *A. abdita* from numerous benthic habitats in San Francisco Bay including transition estuarine, margin estuarine, main estuarine and muddy marine, which are not habitat categories typically characterized by physical disturbance (Table 3-17). In their analysis of the use of best professional judgment by benthic taxonomic experts in assessing the condition of benthic infaunal communities, Weisberg *et al.* (2008) reported that nine surveyed California "expert benthic ecologists" considered the presence of *C. capitata* (complex), oligochaetes, *Mediomastus* spp., and *A. brevis* among the tolerant taxa commonly observed in stressed environments. Weisberg *et al.* also reported that Ophiuroids, Amphipoda, Mollusca, and *A. abdita* were taxa that were considered more sensitive to environmental stress, primarily organic enrichment or elevated contaminants.

The high gravel content of sediments in Cluster 5 (sites 7779W-02 and 7779W-04), as well as at sites 7779W-01 and 2036-01 (Table 3-2), associated with higher numbers of taxa and densities of organisms (Table 3-1), could suggest a more stable benthic environment at those sites. Gravels remain in place under strong currents that would cause smaller particle sizes to be resuspended. These same currents could provide a natural physical disturbance at sites with finer sediments, which could account for the lower numbers of organisms and taxa at those sites. Moreover, the clustering of recently mined sites from within mining leases with sites that had never been mined, both within leases and from control areas, suggests that the factors causing the relatively low number of taxa and organism densities at many sites were apparently widespread over the study area.

In fact, data from Thompson *et al.* (2000) suggest that benthic habitats with relatively low numbers of taxa and low organism densities are present in other areas of Central Bay. The single Central Bay site used to characterize the Marine Sandy habitat in Thompson *et al.* (2000) was near Red Rock, approximately 7 km north of the current study area near the Richmond Bay Bridge. The organism densities, number of taxa, and physical characteristics of the Red Rock site were similar to, but generally lower than, averages for Central Bay sites that had been mined in the 36 months prior to sampling (Table 3-18).

We are aware of data from only one other study for the deeper and coarser sediment seafloor areas of Central Bay that were sampled in the current study. This study was conducted by MEC (1990) for Tidewater Sand and Gravel Company in the Point Knox Shoal area of Central Bay that encompasses CSLC leases 709 N, 7779E and 2036. This study was extremely limited in scope and depth, collecting only five benthic samples and analyzing organisms only to higher taxonomic classifications, such as total polychaetes, isopods and clams. A total of 86 organisms were reported and for three of the five samples, nematodes were the dominant infaunal taxon. They also reported the occurrence of small rocks and shell debris with live epifauna, including hydroids, barnacles (as observed in the current study) and bryozoans.

The general absence of previous benthic sampling efforts in this area of Central Bay could account for the fact that the current study had only five of the 15 most abundant taxa in common with previously reported "representative infauna" for Central Bay and eight taxa that were observed in the current study and not reported in both NOAA (2007) and Thompson *et al.* (2004) (Table 3-17). The seven taxa found in common with Thompson *et al.* (2004) were reported in comparable densities to those observed in the current study (Table 3-18).

Newell *et al.* (1998), in addition to his discussions on benthic recovery rates following aggregate mining and the effects of life history strategies on natural succession, suggest that benthic infaunal communities are not necessarily as correlated with sediment grain size composition and organic carbon concentration as much as they are to the physical conditions that cause differences in these sediment characteristics. In this hypothesis, sediment disturbance is a key ecological factor that results in sediment grain size differences. He argues that in higher energy environments, such as those caused by high currents or wave action, bottom sediments are regularly disturbed and the finer sediment fractions washed away or moved back and forth on the seafloor. As a result, Newell *et al.* (1998) assert that only those benthic organisms that are able to cope with an unstable habitat are able to colonize these locations. These taxa are typically suspension filter feeders like bivalves and tubeworms and larger opportunistic scavengers like some polychaetes and amphipods. Other taxa that are able to cope with a physically disturbed environment are early colonizers (r-species) that frequently reproduce with large broods, such as the polychaete *C. capitata* (complex).

Table 3-17. Characteristics of the most abundant Central Bay taxa in this study, as described in three other studies

Taxon	Group	Newell *et al.* (1998)[1]	Thompson *et al.* (2000)[2]	NOAA (2007)[3]
Nematoda	Nematoda	NR[4]	M-s, M-md, E-mn, E-mr	NR[4]
Heteropodarke heteromorhpha	Polychaeta	NR[4]	M-s	E-dw
Photis spp.	Amphipoda	NR[4]	M-md	NR[4]
Nutricola spp.	Bivalvia	NR[4]	NR[4]	NR[4]
Capitella capitata (complex)	Polychaeta	Early colonizer	NR[4]	NR[4]
Glycinde spp.	Polychaeta	NR[4]	NR[4]	E-h, E-ss
Gnathopleustes pugettensis	Amphipoda	NR[4]	NR[4]	NR[4]
Oligochaeta	Oligochaeta	NR[4]	FB-m, FB-s, E-t, E-mn, E-mr, M-s, M-md	O-c, O-ce, M-sc, M-ss, P-c, P-sc, E-sc, E-h, E-ss
Armandia brevis	Polychaeta	NR[4]	NR[4]	NR[4]
Glycera spp.	Polychaeta	NR[4]	M-s	P-c
Megamoera subtener	Amphipoda	NR[4]	NR[4]	NR[4]
Mediomastus spp.	Polychaeta	NR[4]	E-t, E-mn, M-s, M-md	E-dw, E-sc, E-h, E-ss
Ampelisca abdita	Amphipoda	Early colonizer	E-t, E-mn, E-mr, M-md	M-ce, M-sc, P-c, P-sc, P-ss, E-dw, E-sc, E-h, E-ss
Mactridae	Bivalvia	NR[4]	NR[4]	NR[4]
Leptosynapta spp.	Holothuria	NR[4]	NR[4]	NR[4]

Note [1]: The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed

Note [2]: Results of the Benthic Pilot Study 1994-1997 Part 1–Macrobenthic Assemblages of the San Francisco Bay-Delta, and their Responses to Abiotic Factors; E - Estuarine, FB - Fresh-brackish, M - Marine; mr - margin, mn - main, md - muddy, s - sandy, t - transition

Note [3]: Report on the Subtidal Habitats and Associated Biological Taxa in San Francisco Bay; O - Oligohaline (0.5 - 5.0 ppt), M - Mesohaline (5.0 - 18.0 ppt), P - Polyhaline (18.0 - 30.0 ppt), E - Euhaline (30.0 - 35.0 ppt; c - channel, ce - channel edge, sc - slough channels, ss - shallow subtidal, dw - deep water, h - harbors
Note [4]: Not reported

Table 3-18. Comparisons of densities for the most abundant taxa found in the current study with results from Thompson *et al.* (2000)

Taxa	Group	Mean Number per Sample ($0.05m^2$)	
		Average for Mined Sites in Current Study	Thompson *et al*, for Marine Sandy habitat (RMP Site BC60 – Red Rock, 1994–1997)
Nematoda	Nematoda	1,343	8
Heteropordarke heteromorpha	Polychaeta	95	18
Photis spp.	Amphipoda	13	0
Nutricola spp.	Bivalvia	281	NR[1]
Capitella capitata (complex)	Polychaeta	28	NR[1]
Glycinde spp.	Polychaete	142	NR[1]
Gnathopleustes pugettensis	Amphipoda	5	NR[1]
Oligochaeta	Oligochaeta	111	1
Armandia brevis	Polychaetea	85	NR[1]
Glycera spp.	Polychaete	21	3
Megamoera subtener	Amphipoda	15	NR[1]
Mediomastus spp.	Polychaete	93	1
Ampelisca abdita	Amphipoda	75	0
Mactridae	Polychaeta	15	NR[1]
Leptosynapta spp.	Holothuria	3	NR[1]
Total Number of Taxa	-	15	7
Total Organism Densities	-	155	35
Depth	-	24	11
% Gravel	-	20	6
% Sand	-	77	84
% Silt		3.5	2.8
% TOC	-	0.3	0.4

Note[1]: Not reported

In contrast with Newell *et al.* (1998), we have reported high specificity of numerous taxa for narrow ranges of sediment grain size, and other studies also have documented the importance of sediment characteristics for controlling the distribution of benthic infauna in the absence of variation in physical factors, such as currents or waves (Osenberg *et al.* 1992; Pinedo *et al.* 2000; Spies *et al.* 1988). For example, in an experiment in the Santa Barbara Channel, Spies *et al.* (1988) found differences in recruitment patterns of meiofauna, depending upon the amount and type of organic enrichment within a small area, that would not have exhibited differences in currents or waves. Moreover, Pinedo *et al.* (2000) found that the densities of an infaunal polychaete varied according to the availability of sediment particles of the size it required to construct its tube across an area that likely did not have large variation in currents.

Benthic habitat instability, as described by Newell *et al.* (1998) results in several community and ecological conditions. Benthic infaunal communities in unstable environments, such as those that occur in the shallow nearshore sandy coastal environments where wave action constantly keeps surface sediments in motion, tend to be low in number of species and individual abundances. Newell *et al.* (1998) further suggests that, because of the ongoing instability in these coarser sediment areas of the seafloor where aggregate mining generally occurs, the resident infaunal communities are never able to progress beyond an early or moderate ecological stage of development.

The area of Central Bay where sand mining occurs is characterized by high currents (NOAA 2007), which was substantiated by surface currents in excess of 2 knots observed during field sampling for the current study (Table 2-4). The high percentage of coarser sediments in many of the collected samples throughout the area where sand mining occurs indicates that sufficient energy is present to prevent the finer fractions from being deposited. Moreover, high-resolution, multi-beam side scan sonar mapping of Central Bay in 1997 and again in 2009 (USGS 2009), shows the presence of sand waves throughout the area where sand mining occurs (Figure 3-3). Many of the samples collected in this study came from areas with large sand waves (Figure 3-4).While this study did not directly measure currents, there is evidence that the sand mining leases in Central Bay are exposed to strong currents, which could provide a natural, ongoing disturbance that masks the effects of sand mining.

3.2 Delta

3.2.1 Characterization of Delta Benthic Habitats and Biological Communities

From the 15 samples collected from the Middle Ground Shoal and Suisun Marsh mining leases and three control areas, 16 taxa were identified, a substantially lower number than observed in Central Bay. Benthic communities in the Delta were numerically dominated by bivalvia, followed by polychaeta and amphipoda (Table 3-19), which averaged 369, 37 and 25 animals/m^2, respectively. Total organism densities averaged 472/m^2.

There were relatively smaller differences among sites in the numbers of taxa and numbers of organisms in the Delta than in Central Bay (Table 3-1 and Table 3-19). Site 7781E-02 had greater than 800 organisms/m^2 and 7 taxa. Site DCMG-03, located in the control area closest to Middle Ground Shoal (Figure 2-2), also had greater than 800 organisms/m^2, but had only 4 taxa. In contrast, site 7781W-01 had only 54 organisms/m^2 and 2 taxa and site DCMG-05 had only 325 organisms/m^2 and 3 taxa.

There were large differences among Delta sample sites in sediment grain size composition (Table 3-20), especially in the proportions of coarse, medium and fine sands. Site 7781W-01 had nearly 70% coarse sand, approximately 20% medium sand and <1% fine sand, whereas Site 7781E-05 had <1% coarse sand, <2% medium sand and nearly 90% fine sand. This latter sample was the only sample collected in the San Joaquin River, at the southern extent of the mining lease (Figure 2-2). Sites 7781W-02, 7781E-02, 7781E-03, 7781E-04, MS-01, DCSM-01, DCSM-02, DCMG-04 and DCMG-05 all had 50–70% medium sand.

Statistical multivariate clustering of sites based upon organism abundances revealed three groupings, which did not correspond to mining lease or control sites (Table 3-19 and Figure 3-5). Clusters 1 and 3 had at least two control sites combined with lease sites.

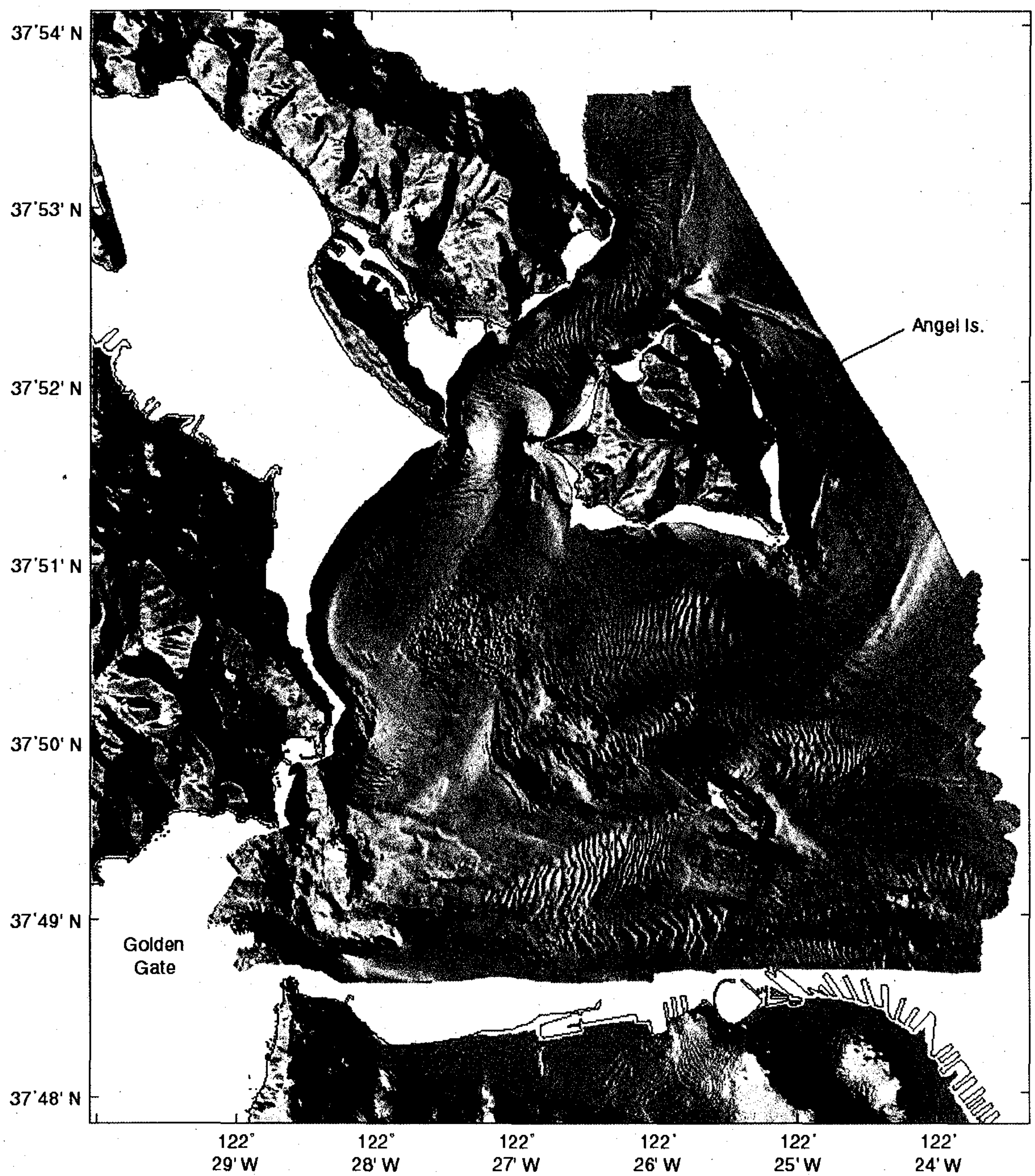

Figure 3-3. Seafloor map of Central San Francisco Bay, illustrating standing sand waves (USGS 2009)

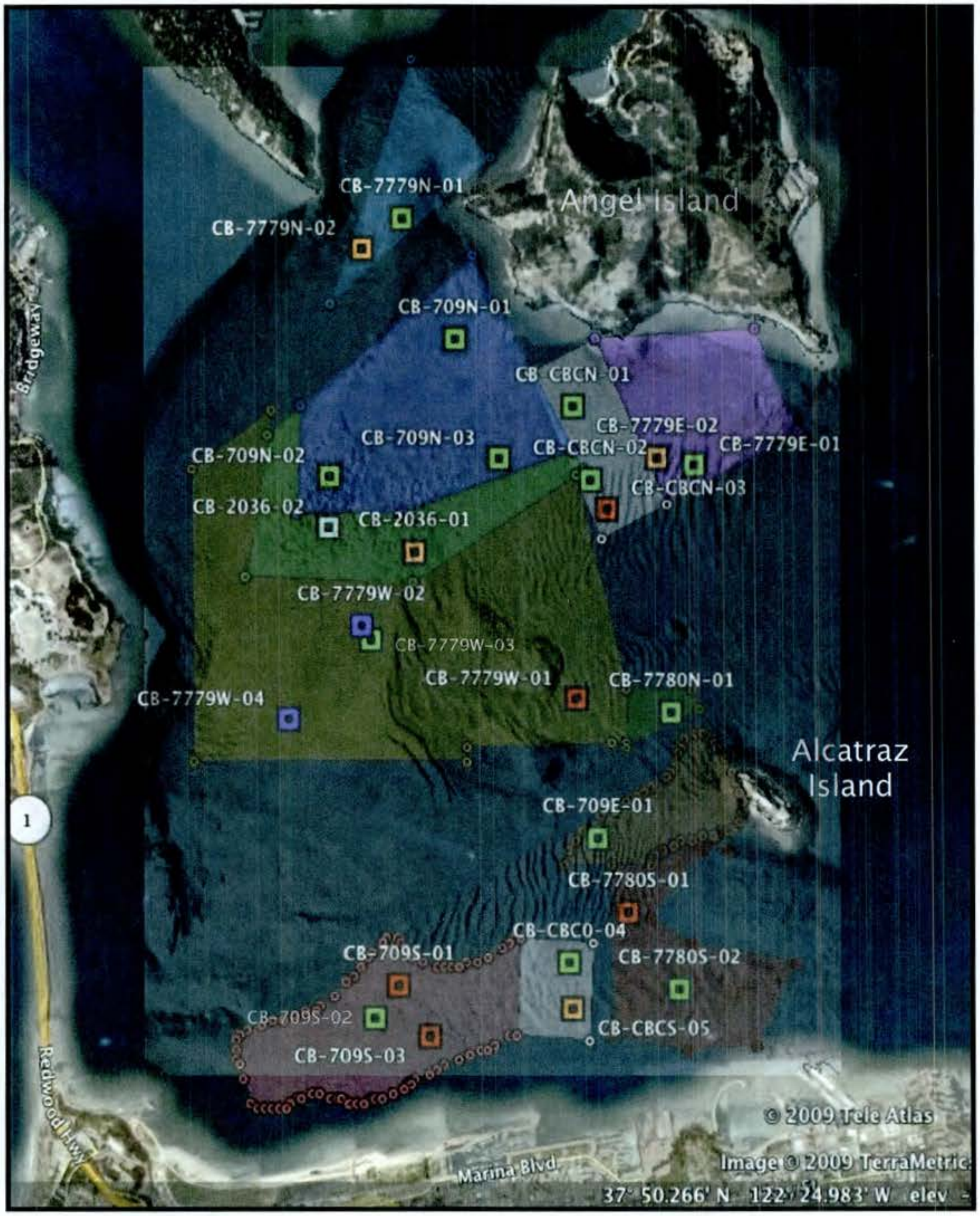

Figure 3-4. Overlay of survey station locations (squares) relative to standing sand waves and other seafloor microhabitats in Central Bay. Colors of square site symbols correspond to clusters in Figure 3-1.

Table 3-19. Organism densities and numbers of taxa collected in benthic samples from the Delta

	Number of Organisms per Meter² → Lease-Site	D-7781W-01	D-7781W-02	D-7781E-01	D-7781E-02	D-7781E-03	D-7781E-04	D-7781E-05	D-MS-01	D-MS-02	D-MS-03	D-DCSM-01	D-DCSM-02	D-DCMG-03	D-DCMG-04	D-DCMG-05	Overall Average	>0.50% of Total Abundances or >10% of All Samples
Nemertea	Nemertea Unidentified	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	1	
Annelida	Polychaeta	0	90	18	126	36	99	32	36	10	18	18	10	36	7	18	37	
	Dorvillea longicornis	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	1	
	Glycinde picta	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	1	
	Marenzelleria viridis	0	90	18	90	36	9	32	36	10	18	18	10	36	7	18	29	X
	Mediomastus spp	0	0	0	18	0	54	0	0	0	0	0	0	0	0	0	5	X
	Sphaerosyllis californiensis	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	1	
Arthropoda	Cirripedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
	Balanus sp. A	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
	Isopoda	0	18	0	18	0	0	0	18	0	0	0	0	0	0	0	4	
	Synidotea laevidorsalis	0	18	0	18	0	0	0	18	0	0	0	0	0	0	0	4	X
	Amphipoda	18	36	18	54	36	0	54	54	18	18	0	18	0	36	18	25	
	Americorophium spinicorne	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	1	
	Americorophium stimpsoni	0	18	0	0	0	0	36	0	0	0	0	0	0	0	0	4	X
	Gammarus daiberi	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	1	
	Grandidierella japonica	18	18	0	36	36	0	0	36	0	0	0	0	0	0	18	11	X
	Phoxocephalidae unidentified*	0	0	0	0	0	0	0	18	18	18	0	0	0	36	0	6	X
	Tritella spp.	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	1	
Mollusca	Bivalvia	36	433	487	523	271	343	271	325	433	180	469	144	776	578	271	369	
	Corbicula fluminea	0	0	0	0	0	0	217	0	0	0	72	0	0	0	0	19	X
	Corbula spp.	36	433	487	523	271	343	54	325	433	180	397	144	776	578	271	350	X
	Number of Taxa per grab**	2	6	3	7	4	7	6	5	5	5	5	4	4	5	3	5	
	Total Number of Organisms/m²	54	667	541	847	379	559	389	469	471	234	505	164	848	626	325	472	

* Very tiny specimens
** Not adjusted for "spp." entries or "+" entries

= Cluster 1
= Cluster 2
= Cluster 3
=4–5 taxa and 400–599 organisms/m²
=>5 taxa and >599 organisms/m²

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Table 3-20. Depths and sediment characteristics of samples collected in the Delta

Physical Factor	Site: D-7781W-01	D-7781W-02	D-7781E-01	D-7781E-02	D-7781E-03	D-7781E-04	D-7781E-05	D-MS-01	D-MS-02	D-MS-03	D-DCSM-01	D-DCSM-02	D-DCMG-03	D-DCMG-04	D-DCMG-05
sample depth, MLLW, corrected (m)	15.4	15.8	11.6	10.3	16.4	18.8	5.0	12.3	11.0	11.4	9.3	8.5	12.0	10.8	13.4
TOC (%)	0.28	0.27	0.18	0.16	0.15	0.15	0.29	0.26	0.58	0.21	0.35	0.35	0.34	0.15	2.71
Gravel, Medium (%)	0.37	0.80	1.13	0.68	0.00	0.00	0.00	0.61	0.26	2.13	0.00	0.00	0.41	0.56	0.00
Gravel, Fine (%)	1.16	1.49	1.33	1.31	0.01	0.17	0.16	0.45	0.16	1.21	0.02	0.01	0.17	0.19	0.88
Sand, Very Coarse (%)	7.00	1.27	6.37	1.87	0.14	0.80	0.34	3.00	0.36	2.38	0.88	0.88	0.31	0.30	0.88
Sand, Coarse (%)	69.21	9.51	24.28	11.96	3.50	5.85	0.35	23.21	2.16	4.31	13.91	31.50	1.94	1.71	7.57
Sand, Medium (%)	20.59	62.03	46.85	64.10	67.06	55.93	1.70	53.77	35.97	32.04	64.39	61.06	33.59	53.98	61.36
Sand, Fine (%)	0.11	23.86	17.78	19.30	28.32	36.18	89.61	17.26	58.50	36.74	14.56	6.22	56.76	30.88	27.15
Sand, Very Fine (%)	0.05	0.26	0.26	0.33	0.37	0.35	3.79	0.94	0.68	1.09	1.38	0.12	0.85	0.95	0.21
Silt (%)	0.84	0.35	1.26	0.16	0.35	0.41	2.44	0.35	0.93	10.80	2.87	0.06	3.03	5.49	1.16
Clay (%)	0.68	0.43	0.74	0.29	0.27	0.32	1.60	0.42	0.99	9.31	1.98	0.15	2.94	5.94	0.80
Mining Status	No	No	No	Possible	Yes	Yes	No	Possible	Possible	Possible	No	No	No	No	No
Estimated months since last mining	60	60	60	36	13	10	60	36	36	36	60	60	60	60	60

= Cluster 1
= Cluster 2
= Cluster 3

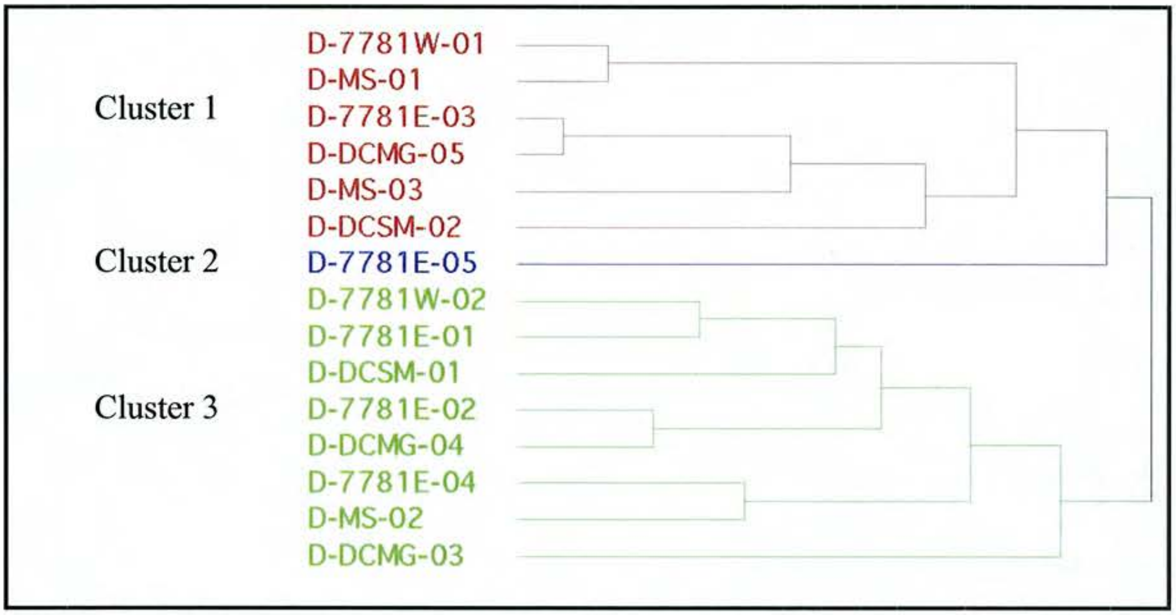

Figure 3-5. Multivariate statistical clusters of Delta sites (Ward's minimum variance method) based upon abundances of common or abundant taxa

Densities of many of the Delta benthic taxa differed among clusters (Figure 3-6). Cluster 1 had medium densities of the bivalve *Corbula* spp. and low densities of the polychaete *Marenzalaria viridis* and the amphipod *Grandiphoxus grandis*. Cluster 2 had high densities of *M. viridis* and the bivalve *Corbicula fluminea*, with low densities of the amphipod *Americorophium stimpsoni* and *Corbula* spp. Cluster 3 had high densities of *Corbula* spp. and medium densities of *Marenzalaria viridis*.

ANOVA confirmed differences among clusters in densities of many of the most common and abundant Delta taxa (Table 3-21). *M. viridis*, *A. stimpsoni* and *C. fluminea* had significantly higher densities in Cluster 2 than in either of the other clusters, whereas *Corbula* spp. had significantly higher densities in Cluster 3. The total number of organisms was greater in clusters 2 and 3 than in Cluster 1.

Some of the organism differences among clusters could have been due to differences in depth or grain size (Table 3-22). ANOVA and Tukey's tests revealed that Cluster 2 had greater percentages of fine and very fine sands and lower percentages of medium sand than either of the other clusters. Finally, there were no differences among clusters in the estimated months since mining.

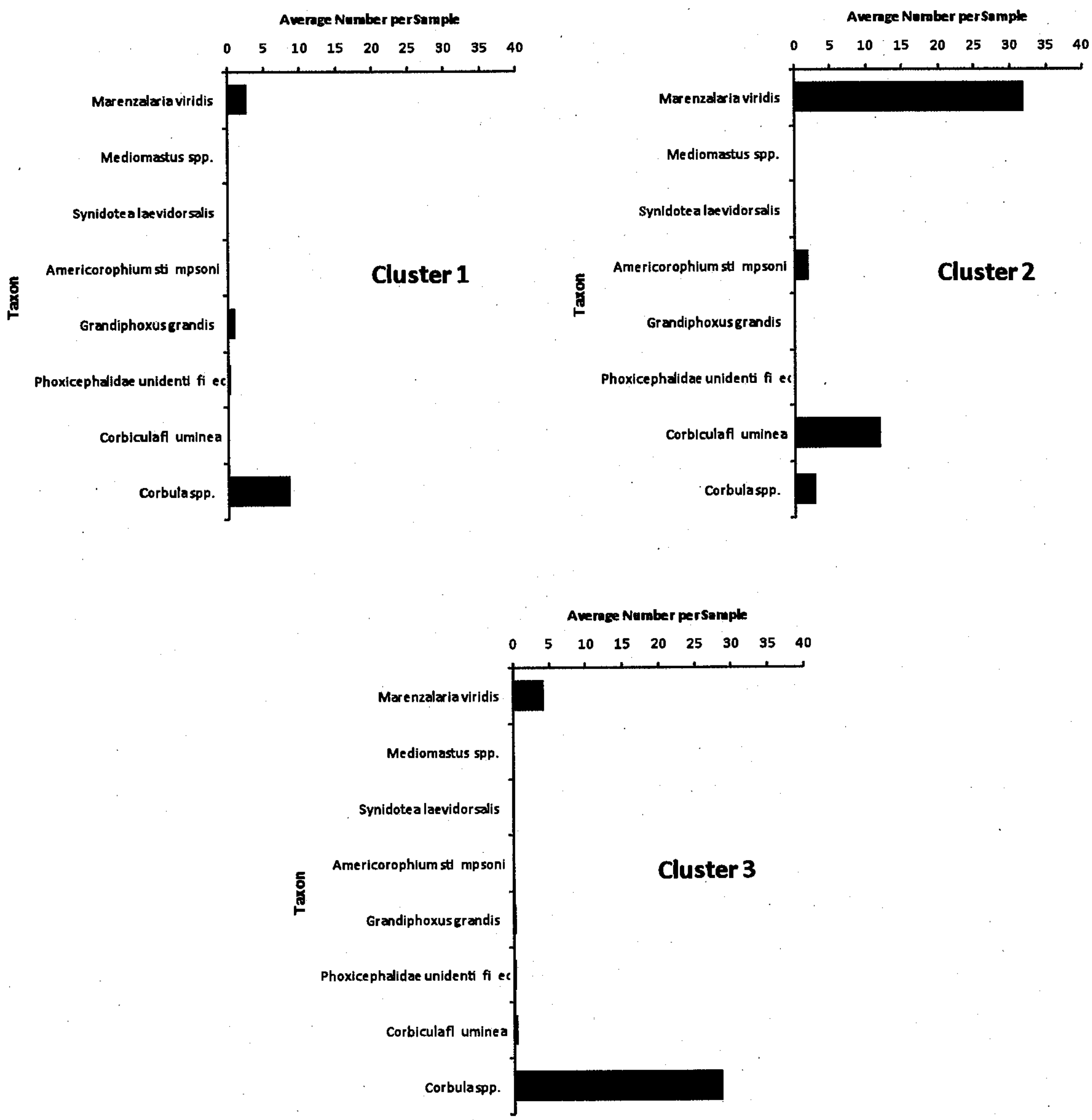

Figure 3-6. Densities of the most common and abundant benthic taxa in three clusters identified for Delta sites

Table 3-21. ANOVA results for differences in organism abundances among clusters of Delta sites

Taxa[1]	Group	(r^2)	(p)	Tukey Results[2]
Corbula spp.	Bivalvia	0.7210	0.0005	3>1=2
Marenzalaria viridis	Polychaeta	0.8303	<0.0001	2>3=1
Corbicula fluminea	Bivalvia	0.9021	<0.0001	2>3=1
Grandiphoxus grandis	Amphipoda	0.1797	0.3047	1=3=2
Phoxicephalidae unidentified	Amphipoda	0.0234	0.8674	3=1=2
Mediomastus spp.	Polychaeta	0.1045	0.5158	3=2=1
Synidotea laevidorsalis	Isopoda	0.0278	0.8455	3=1=2
Americorophium stimpsoni	Amphipoda	0.8011	<0.0001	2>3=1
Total Polychaeta	Polychaeta	0.7742	0.0001	2>3=1
Total Amphipoda	Amphipoda	0.2067	0.2492	2=1=3
Total Bivalvia	Bivalvia	0.7082	0.0006	3>1, 3=2, 2=1
Total Number of Organisms	-	0.8225	<0.0001	2=3>1
Total Number of Taxa	-	0.2972	0.1205	2=3=1

Note [1]: Taxa listed in order of overall average densities
Note [2]: Highest mean density is on the left and lowest is on the right

Table 3-22. ANOVA results for differences in physical factors among Delta clusters

Factor	(r^2)	(p)	Tukey Results[1]
Months since mining	0.0489	0.7403	2=3=1
Depth	0.3288	0.0914	1=3=2
% Total Organic Carbon	0.0930	0.5567	1=2=3
% Medium Gravel	0.0494	0.7377	1=3=2
% Fine Gravel	0.0418	0.7740	1=3=2
% Very Coarse Sand	0.0735	0.6325	1=3=2
% Coarse Sand	0.2004	0.2613	1=3=2
% Medium Sand	0.4510	0.0274	3=1>2
% Fine Sand	0.5826	0.0053	2>3=1
% Very Fine Sand	0.8213	<0.0001	2>3=1
% Silt	0.0076	0.9551	2=1=3
% Clay	0.0025	0.9853	1=3=2

Note [1]: Highest mean value is on the left and lowest is on the right

3.2.2 Effects of Sand Mining on Delta Bottom Sediments and Benthic Communities

As with data for Central Bay, the clustering of leased and control sites suggested sand mining does not appear to be exerting a strong influence on Delta benthic communities. Nevertheless, additional statistical tests were performed to examine this possibility, assess whether sand mining is associated with differences in sediment grain size, and to help determine the factors associated with differences in taxa densities. ANOVA and Tukey's tests were performed to test for differences in organism abundances and sediment characteristics between samples from leased and control sites, as well as among sites with different times since they were last mined (*i.e.*, those known to have been mined in the last 36 months, those that might have been mined within the last 36 months and those that were not mined within the last 36 months).

None of the most common and abundant Delta taxa varied between leased and control sites (Table 3-23), and only one differed among sites that had been, had possibly been, or never had been mined in the previous 36 months (Tables 3-24). Only the polychaete, *Mediomastus* spp. differed among sites that had or had not been mined, with greater densities occurring at sites that had been mined (Table 3-24).

There were no apparent effects of sand mining on physical habitat characteristics at sand mining lease locations. ANOVAs performed to test for differences in months since mining, site depth, grain size and total organic carbon revealed that sites located within mining leases differed from control sites only for months since mining, with samples from control sites having more months since mining than sites on leases (Table 3-25). Moreover, sites known to have been mined in the previous 36 months had significantly fewer months since mining than either sites that had not been mined or sites that possibly were mined and significantly greater depth than did sites that had either not been mined or possibly were mined (Table 3-26).

As was the case for Central Bay, the absence of statistically significant effects on Delta benthic organism densities associated with either being in a lease or assumed recent antecedent mining activity could be due to uncontrolled confounding factors. Stepwise linear regressions were performed to investigate whether any combination of months since mining, sediment grain size, total organic carbon concentration and site water depth could account for significant amounts of variation in Delta organism densities. Linear regressions for Delta benthic data also included longitude as a possible independent variable, which served as a surrogate for any salinity gradient effects that occur in that part of the Delta.

Stepwise linear regressions detected few Delta taxa for which highly significant regression models occurred (Table 3-27). Only the polychaete *Marenzalaria viridis*, the isopod *Synidotea laevidorsalis*, the amphipod *Americorophium stimpsoni* and the bivalve *Corbicula fluminea* exhibited highly significant regressions and none of them respond to any variables except sediment grain size or longitude, the surrogate for the Delta salinity gradient. *M. viridis* and *C. fluminea* both responded negatively to longitude, which suggests lower densities for these taxa at more western sites with higher salinities. Longitude was the most important variable and second-most important variable for *M. viridis* and *C. fluminea*, respectively (Table 3-28). The remainder of the three most important variables for these four taxa ranged from medium gravel to silt, with both positive and negative correlations occurring (Table 3-28).

Table 3-23. ANOVA results for differences in organism abundances between leased and control sites in the Delta

Taxa[1]	Group	(r^2)	(p)	Tukey Results[2]
Corbula spp.	Bivalvia	0.1195	0.2069	Control=Leased
Marenzalaria viridis	Polychaeta	0.0231	0.5891	Leased=Control
Corbicula fluminea	Bivalvia	0.0037	0.8288	Leased=Control
Grandiphoxus grandis	Amphipoda	0.1250	0.1961	Leased=Control
Phoxicephalidae unidentified	Amphipoda	0.0063	0.7794	Control=Leased
Mediomastus spp.	Polychaeta	0.0597	0.3801	Leased=Control
Synidotea laevidorsalis	Isopoda	0.1250	0.1961	Leased=Control
Americorophium stimpsoni	Amphipoda	0.0682	0.3472	Leased=Control
Total Polychaeta	Polychaeta	0.0357	0.5003	Leased=Control
Total Amphipoda	Amphipoda	0.1731	0.1230	Leased=Control
Total Bivalvia	Bivalvia	0.1199	0.2061	Control=Leased
Total Number of Organisms	-	0.0164	0.6495	Control=Leased
Total Number of Taxa	-	0.0737	0.3276	Leased=Control

Note [1]: Taxa listed in order of overall average densities
Note [2]: Highest mean density is on the left and lowest is on the right

Table 3-24. ANOVA results for differences in organism abundances Delta sites that were mined, possibly were mined and were not mined in the previous 36 months

Taxa[1]	Group	(r^2)	(p)	Tukey Results[2]
Corbula spp.	Bivalvia	0.0187	0.8926	No=Yes=Possible
Marenzalaria viridis	Polychaeta	0.0133	0.9229	No=Yes=Possible
Corbicula fluminea	Bivalvia	0.796	0.6079	No=Possible=Yes
Grandiphoxus grandis	Amphipoda	0.1667	0.3349	Yes=Possible=No
Phoxicephalidae unidentified	Amphipoda	0.1927	0.2768	Possible=No=Yes
Mediomastus spp.	Polychaeta	0.4123	0.0412	Yes>No, Yes=Possible, Possible=No
Synidotea laevidorsalis	Isopoda	0.2130	0.2377	Possible=Yes=No
Americorophium stimpsoni	Amphipoda	0.0909	0.5645	No=Possible=Yes
Total Polychaeta	Polychaeta	0.0137	0.9206	Yes=No=Possible
Total Amphipoda	Amphipoda	0.1731	0.1230	Leased=Control
Total Bivalvia	Bivalvia	0.0489	0.7404	No=Yes=Possible
Total Number of Organisms	-	0.0331	0.8171	No=Yes=Possible
Total Number of Taxa	-	0.2031	0.2560	Yes=Possible=No

Note [1]: Taxa listed in order of overall average densities
Note [2]: Highest mean density is on the left and lowest is on the right

Table 3-25. ANOVA results for differences in physical factors between leased and control sites in the Delta

Factor	(r^2)	(p)	Tukey Results[1]
Months since mining	0.2741	0.0452	Control>Leased
Depth	0.0792	0.3094	Leased=Control
% Total Organic Carbon	0.1608	0.1385	Control=Leased
% Medium Gravel	0.1144	0.2175	Leased=Control
% Fine Gravel	0.1759	0.1196	Leased=Control
% Very Coarse Sand	0.1488	0.1555	Leased=Control
% Coarse Sand	0.0125	0.6917	Leased=Control
% Medium Sand	0.0777	0.3144	Control=Leased
% Fine Sand	0.0145	0.6687	Leased=Control
% Very Fine Sand	0.0033	0.8372	Leased=Control
% Silt	0.0158	0.6551	Control=Leased
% Clay	0.0265	0.5619	Control=Leased

Note [1]: Highest mean value is on the left and lowest is on the right

Table 3-26. ANOVA results for differences in physical factors among Delta sites that were mined, possibly were mined and were not mined in the previous 36 months

Factor	(r^2)	(p)	Tukey Results[1]
Months since mining	0.9990	<0.0001	No>Possible>Yes
Depth	0.4086	0.0428	Yes>No=Possible
% Total Organic Carbon	0.0598	0.6907	No=Possible=Yes
% Medium Gravel	0.2847	0.1340	Possible=No=Yes
% Fine Gravel	0.1419	0.3992	Possible=No=Yes
% Very Coarse Sand	0.0621	0.6806	No=Possible=Yes
% Coarse Sand	0.0785	0.6122	No=Possible=Yes
% Medium Sand	0.0886	0.5731	Yes=Possible=No
% Fine Sand	0.0047	0.9722	Possible=Yes=No
% Very Fine Sand	0.0363	0.8012	No=Possible=Yes
% Silt	0.0862	0.5824	Possible=No=Yes
% Clay	0.0895	0.5698	Possible=No=Yes

Note [1]: Highest mean value is on the left and lowest is on the right

Table 3-27. Highly significant ($p < 0.005$) results from stepwise linear regressions for effects of depth, sediment grain size, total organic carbon and months since mining on organism abundances at Delta sites

Taxa[1]	(r^2)	(p)	Regression Model[2]
Marenzalaria viridis	0.8763	0.0029	y = 7723 – 60.5longitude – 5.39vcsand – 3.27csand – 3.54msand – 3.27fsand – 7.45silt
Synidotea laevidorsalis	0.8088	0.0047	y = 44.1 – 0.536vcsand – 0.441csand – 0.437msand – 0.452fsand – 0.970silt
Americorophium stimpsoni	0.8249	0.0032	y = 0.529fgravel + 0.041csand + 0.039msand + 0.044fsand – 0.566vfsand – 4.34
Corbicula fluminea	0.9537	<0.0001	y =2021 + 2.99vfsand – 16.6longitude

Note [1]: Taxa listed in order of overall average densities
Note [2]: months (months since last mining), depth (site water depth), TOC (total organic carbon), mgravel (medium gravel), fgravel (fine gravel), vcsand (very coarse sand), csand (coarse sand), msand (medium sand), fsand (fine sand), vfsand (very fine sand)

Table 3-28. The first, second and third most influential independent variables for each Delta taxon or group with a highly significant ($p < 0.005$) linear regression, as indicated by their respective partial correlations

Taxa[1]	1st Most Important Variable		2nd Most Important Variable		3rd Most Important Variable	
	Name	Partial Correlation	Name	Partial Correlation	Name	Partial Correlation
Marenzalaria viridis	Longitude	-0.7317	Very coarse sand	-0.6815	Silt	-0.6704
Synidotea laevidorsalis	Silt	-0.8788	Coarse sand	-0.8743	Fine sand	-0.8715
Americorophium stimpsoni	Very fine sand	0.7974	Fine gravel	0.7183	Fine sand	0.6966
Corbicula fluminea	Very fine sand	0.9691	Longitude	-0.8022	NA	-

Note [1]: Taxa listed in order of overall average densities

3.2.3 Data Interpretation

3.2.3.1 Recovery of Delta Benthic Communities following Mining

As with Central Bay benthic communities, substantial variation was evident in the composition of benthic assemblages among Delta sampling sites in mining leases and control areas, as indicated by Table 3-19 and Figure 3-6. Significant differences in organism densities among the three clusters identified among Delta sampling sites always involved Cluster 2, Cluster 3, or both Cluster 2 and Cluster 3, exceeding Cluster 1. The polychaete *Marenzalaria viridis*, the amphipod *Americorophium stimpsoni*, the bivalve *Corbicula fluminea,* and total polychaetes all had significantly higher densities in Cluster 2 than the other two clusters (Table 3-21). This cluster (Figures 3-5 and 3-6) consisted of one sample, which was the eastern-most site on the San Joaquin River. *M. viridis* and *C. fluminea* were also significantly correlated with longitude, which served as a surrogate for the Delta salinity gradient.

In all the other sampled locations represented by Clusters 1 and 2, the invasive Asian clam, *Corbula spp.* was the dominant taxon (Figure 3-6). Most of the individuals collected were larger than the sizing screens used by the sand mining companies to grade and retain extracted sand. It can be assumed that many of the entrained *Corbula* would be discharged in the barge overflow pipe during mining and resettle in recently mined areas. None of this observed variation could be attributed to mining activities, as only densities of the polychaete *M. viridis.* differed significantly between sites that had and had not been mined, with higher densities at mined sites (Table 3-24). Unlike in Central Bay, sediment grain size in the Delta had no apparent correlation with sand mining. Consequently, results for the Delta indicate the predominant factors affecting organism abundances were simply sediment grain size and salinity.

As was found for the Central Bay, comparison of the sites that had recently been mined with sites characterized as possibly mined and never mined indicated that any mining effects on Delta benthic communities are either spatially very limited or of short duration. Sites 7781E-03 and 7781E-04 were mined within 13 and 10 months of sampling, respectively (Table 3-24). Data provided by the lease operator indicated that none of the other sampling sites had been mined within the previous 36 months.

Sites 7781E-03 and 7781E-04 averaged 469 organisms/m^2 and 5.5 taxa per sample, whereas all other sites together averaged 472 organisms/m^2 and 4.6 taxa per sample. Consequently, any potential negative effects of sand mining on Delta benthic communities appear to be either very spatially limited, such that collected samples were collected outside the dredge track, or they become undetectable within two years of mining.

3.2.3.2 Comparison with Other Studies

The taxa and densities of benthic organisms reported by the current study for Delta sites are similar to those reported by two other recent studies (Newell *et al.* 1998; NOAA National Marine Fisheries Service 2007; Thompson & Lowe 2004; Thompson *et al.* 2000). Thompson *et al.* (2000) and NOAA (2007) either separately or together reported the bivalves *Corbula* spp. and *Corbicula fluminea,* the polychaete *Marenzalaria viridis* and *Mediomastus* spp., the amphipods *Grandiphoxus grandis* and *Americorophium stimpsoni* and the isopod *Synidotea laevidorsalis*, from several habitats in the Bay and Delta (Table 3-29). Mean densities for several of these taxa from fresh-brackish sandy habitat reported by Thompson *et al.* (2000) were roughly similar to those reported in the current study (Table 3-30).

Table 3-29. Characteristics of the most abundant Delta taxa in this study, as described in two other studies

Taxa	Group	Thompson *et al.* (2000)[1]	NOAA (2007)[2]
Corbula spp.	Bivalvia	FB-md, FB-s, E-t, M-s, E-mn, E-mr, M-md	O-c, O-ce, M-c, M-ce, M-sc, M-ss, P-c, P-sc, P-ss
Marenzalaria viridis	Polychaeta	FB-md, FB-s, E-mn	O-c, M-c, M-ce, M-sc, M-ss, P-c[2]
Corbicula fluminea	Bivalvia	FB-md, FB-s, E-t	O-c
Grandiphoxus grandis	Amphipoda	E-t, E-mn	NR[3]
Phoxicephalidae unidentified	Amphipoda	NR[3]	NR[3]
Mediomastus spp.	Polychaeta	E-t, E-mn, M-s, M-md	E-dw, E-sc, E-h, E-ss
Synidotea laevidorsalis	Isopoda	NR[3]	M-ce
Americorophium stimpsoni	Amphipoda	NR[3]	O-c, O-ce, M-ss

Note [1]: Results of the Benthic Pilot Study 1994-1997 Part 1–Macrobenthic Assemblages of the San Francisco Bay-Delta, and their Responses to Abiotic Factors; E - Estuarine, FB - Fresh-brackish, M - Marine; mr - margin, mn - main, md - muddy, s - sandy, t - transition

Note [2]: Report on the Subtidal Habitats and Associated Biological Taxa in San Francisco Bay; O - Oligohaline (0.5 - 5.0 ppt), M - Mesohaline (5.0 - 18.0 ppt), P - Polyhaline (18.0 - 30.0 ppt), E - Euhaline (30.0 - 35.0 ppt; c - channel, ce - channel edge, sc - slough channels, ss - shallow subtidal, dw - deep water, h - harbors

Note [3]: Not reported

Table 3-30. Comparisons of densities for the most abundant Delta taxa found in the current study with results from another study

Taxa	Group	Mean Number per Sample ($0.05m^2$)	
		Current Study	Thompson *et al.* (2000) for fresh-brackish sandy habitat
Corbula spp.	Bivalvia	18	1
Marenzalaria viridis	Polychaeta	6	2
Corbicula fluminea	Bivalvia	1	19
Grandiphoxus grandis	Amphipoda	.6	0
Phoxicephalidae unidentified	Amphipoda	.3	NR[1]
Mediomastus spp.	Polychaeta	.3	0
Synidotea laevidorsalis	Isopoda	.2	NR[1]
Americorophium stimpsoni	Amphipoda	.2	NR[1]

Note [1]: Not reported

4 Conclusions

The benthic communities observed in Central Bay and the Delta are generally consistent with those reported in other studies. The Central Bay study area is deeper and contains coarser sediments than typically sampled by other programs and contained numerous taxa that had not been listed as characteristic for Central Bay by previous investigators. In both the Central Bay and Delta, densities of benthic taxa were predominantly correlated with sediment grain size. In the Delta, salinity appears also to be an important variable controlling abundances of some taxa.

Sampling sites in both Central Bay and the Delta that had previously been mined within three years of sampling for the current study exhibited no biological characteristics suggesting effects from sand mining. Some potential effects of aggregate mining that were detected in Central Bay included a reduction in medium sand at sites that had been mined and densities of two taxa (*Nephtys ?californiensis*, and *Megamoera subtener*) and total amphipoda that were positively correlated with the months since mining.

The benthic communities of Central Bay where sand mining occurs does not appear to be highly degraded due to organic enrichment or elevated contaminant levels. This conclusion is based on an assessment of benthic community taxa, relative to their sensitivity or tolerance to environmental stress, using best professional judgment indicators as presented by Weisberg *et al.* 2008.

Strong currents in the mining areas of Central Bay can be assumed not only to affect benthic sediment composition, but associated infaunal organisms as well. The natural disturbance of bottom sediments by strong, tidally induced bottom currents, as indicated by standing sand waves in the Central Bay study area, appears to maintain a dynamic environment that prevents infaunal organisms from establishing a highly developed community, as evident by the low numbers of taxa and low organism densities at many sites. Sample sites that contained high percentages of gravel appeared to support a more developed infaunal community with substantially higher numbers of taxa and total abundances.

Recovery of benthic communities to pre-mining conditions appears to occur within two years. This rapid recovery could be due, in part, to natural environmental conditions that appear to disturb benthic communities throughout this area of Central Bay. Also, rapid recolonization of mined tracks can occur not only by larval recruitment, but also by immigration from surrounding unmined sediments, either through active movement by individual organisms or through transport by slumping sediments. Slumping of unmined sediments into mined areas is one possible explanation for the numerical presence of the bivalve *Nutricola* spp. at a location that was mined within four months before sampling. High abundances of taxa that are not early colonizers could also reflect the difficulty of precisely collecting samples from the small swath of seafloor covered by the mining dredge. Regardless of the cause, high abundances of such taxa indicate that mining disturbances to benthic infauna in Central Bay and the West Delta are probably spatially very small.

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